Research Trends in Science, Technology and Mathematics Education

Review talks delivered at epiSTEME-1,
an international conference to review research on
Science, Technology and Mathematics Education

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edited by

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Contents

Preface

Over the last forty years science, technology and mathematics education have emerged as lively new research areas. The research activity in these areas has been reflected in the launching of literally hundreds of new journals, in science education, mathematics education and, more recently, in design and technology education. Much of this research is carried out at the primary, middle and secondary levels of schooling. Mathematics, science and technology are of course intimately connected: at theoretical as well as practical and application levels, science, technology and mathematics ***(STM)*** are linked via intricate networks of concepts.

Now we find, in investigating the educational issues in ***STM***, that there are a multitude of further uniting themes that originate in the cognitive, pedagogical, historical, philosophical and socio-cultural aspects of Science, Technology and Mathematics Education ***(STME)***. With a view to consolidating research and development activity around these uniting themes, the Homi Bhabha Centre for Science Education (HBCSE) initiated, in December 2004, a series of biennial conferences, named ***epiSTEME***. This book is a collection of the seven review talks delivered at the first conference.

Homi Bhabha Centre for Science Education

The Homi Bhabha Centre for Science Education (HBCSE), a National Centre of the Tata Institute of Fundamental Research, Mumbai, India has, since its inception in 1974, been concerned with improving science education in the country. Research into students' learning, which has been pursued at HBCSE over the last several years, encompasses cognitive and pedagogical studies, attitudinal studies, and studies of gender issues in science education as well as educational implications of history and philosophy in the contexts of science, mathematics and technology education.

The science education research at HBCSE focuses on alternative conceptions in topics of school and college science, students' epistemologies, notations and representations, cross-cultural issues and curricular matters. Mathematics education research at HBCSE is concerned with the place of mathematics in the school curriculum and the pedagogical issues of how best it can be taught and learnt as well as with the cognitive issues of concept learning and conceptual change in mathematics. Technology education research at HBCSE explores the possibility of introducing technology education within the Indian school curricula and addresses key issues in the development of curricular elements for technology education at the school level, including cognitive, socio-cultural and gender aspects.

Though several curriculum development and teacher professional development efforts in science and mathematics education exist in India, HBCSE is unique in its emphasis on building up a body of research in these areas in the Indian context. Technology education at the school level is an area that HBCSE has pioneered in the country. The development projects at HBCSE gain substantially from research and scholarship in ***STME***. It is felt however that research in ***STME*** needs to be encouraged also in other parts of the country. Such research is of course worthwhile to pursue for its own sake. But more vitally, when National and State level education programs are taken up they need to draw on expertise of such cross-disciplinary kind: that combines conceptual depth with field-level experience. ***STME*** research would provide this much needed local resource for guiding educational programs.

The *epiSTEME* series

On this background HBCSE proposed a series of biennial conferences with the aim of promoting scholarship in cognitive, social, historical and philosophical aspects of science, mathematics and technology education. The conferences are expected to survey the global progress of research in science, technology and mathematics education and to strengthen linkages among research groups in this field across the world. The outreach of the conferences is global, yet their major aim is to nurture a research community in India. The uniqueness of the ***epiSTEME*** concept is the integration of issues related to science education, technology education and mathematics education within a single conference.

Epistemology is the branch of philosophy that studies the nature, origin, and scope of knowledge. The Greek word *episteme* that refers to *science* (as opposed to *techne*) is often translated as *knowledge*. Thus ***epiSTEME*** at one level connotes systematic study or knowledge. As an acronym ***epiSTEME*** suggests a meta-view of ***S***cience, ***TE***chnology and ***M***athematics ***E***ducation.

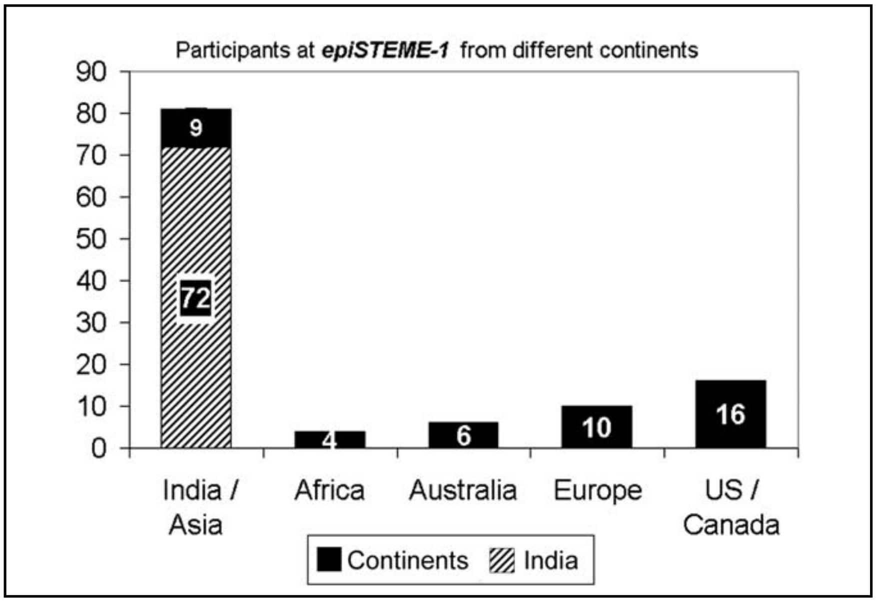
The first conference

Conference ***epiSTEME-1*** was planned around two broad groups of themes which are reflected also in the organisation of the present volume. Themes in the first group were of a theoretical nature and included *history and* *philosophy of science and its implications for STME; knowledge representation; models of cognition; social, cultural and language issues; and affect in learning.* Another group of themes, related with practice, had to do with *trends in science, mathematics and technology education research*. Though the themes were diverse, all presentations took place in plenary sessions. Despite the pressure to include a larger number of presentations, parallel sessions were avoided. Thus the interconnections between theory and practice as also between Science, Technology and Mathematics education were brought out through discussions within a remarkably interdisciplinary group of researchers. Many participants provided feedback that this integrative aspect of the conference had made the interactions especially interesting and fruitful.

The conference had seven review talks in which leading scholars in the field gave overviews of selected areas of current work. These review talks form the substance of this volume. Sessions on paper and poster presentations were organized to complement the reviews and to identify promising directions for future research. The extended abstracts and complete papers in some cases have been brought out as a web publication. They can be viewed at *http://www.hbcse.tifr.res.in/episteme1/conf_proc/.*

Venue, participation and support

Conference ***epiSTEME–1*** was held during December 13-17, 2004 at the International Centre, Dona Paula, Goa, India. Funding support was provided by HBCSE, Department of Science and Technology (DST) the Government of India, International Centre for Theoretical Physics (ICTP) Trieste, Italy and the Indo-US Forum.



The conference brought together scholars from eighteen countries in five continents. Of the 117 researchers and educators attending, 45 were from outside India and 72 from institutions within India.

Among the participants, only 9 were from developing countries other than India and 36 were from developed countries. Though considerable efforts were made to allow participation from developing countries other than India, only nine such participants managed to attend. The main reason was perhaps that ***STME*** research is less prevalent in developing countries. But there was also a limitation in the available means of communicating the announcement of the conference across the developing world. Another potential problem was funding; participation from Africa was made possible only due to travel support received from ICTP.

Participants from the developed as well as the developing world appreciated the international representation at the conference. Cross-national links were established amongst science, technology and mathematics educators and several reciprocal international visits resulted as an outcome of the conference.

Schedule of the conference

The schedule of the conference was a fairly packed one and composed largely of plenary sessions. Besides the 7 review talks, the conference program included 26 papers, 39 posters and a satellite workshop on technology education comprising of two evening sessions. Details of the conference program (Appendix B) and a list of participants (Appendix C) are given at the end of this volume.

Related workshops

In the week prior to the main conference, during December 6-10, 2004, two workshops were organised at HBCSE: one on the *history and philosophy of science and its implications for science teaching*, by Michael Matthews of the University of New South Wales, and another on *mathematics education research*, by Kaye Stacey of the University of Melbourne. The participants at the workshops included the research students and faculty of HBCSE and a few interested students of Mumbai University. During the conference, a satellite workshop was held by Marc de Vries of the Eindhoven University of Technology, the Netherlands on the *philosophy of technology for research in technology education*.

The pre-conference workshop on history and philosophy of science conducted by Michael Matthews (December 6-10, 2004) was based on his book, ***Time for Science Education: How Teaching the History and***

Philosophy of Pendulum Motion Contributes to Science Literacy, published by Kluwer Academic Publishers, New York, 2000. The workshop discovered the relevance of history and philosophy of science in science teaching through the case of pendulum motion. HBCSE research students and faculty members presented chapters from the book and the discussions were moderated by Michael Matthews. The 10 presentations in this pre-conference workshop included; Navigation and the longitude problem, Ancient and medieval timekeeping, Galileo and the pendulum clock, Galileo's analysis of pendulum motion, Christian Huygens and the pendulum clock, The pendulum in Newton's physics, Clocks and culture, Clock analogy in philosophy and theology, Science education, teacher education and culture, and Science and Philosophy: some lessons from the history of pendulum motion.

The pre-conference workshop on ***mathematics education research*** had as its focus algebra education and consisted of presentations by the mathematics education research group members of HBCSE and by Kaye Stacey. Stacey gave two talks, the first, "Preparation for algebra in the primary grades", highlighted the discontent with the existing (traditional) algebra and the need for change. She made clear distinctions between algebraic thinking and learning formal bits of algebra and gave examples from research in what has been called 'early algebra'. She explained how early algebra paves the way for algebraic thinking and formal algebra.

In another talk, Stacey focused on the role of Computer Algebra Systems (CAS) in the teaching and learning of algebra. She highlighted the goals of introducing technology in the teaching and learning of algebra and the challenges and issues that this brings. CAS aims at enhancing students' ability to solve more real world problems and provides added advantage to those who have inadequate skills, thus utilizing both its functional and pedagogical value. However, it also brings with it issues of changes required in the curriculum. A technology intensive course needs a change from routine symbol manipulation in the curriculum to understanding function relationships and developing new insights.

During this workshop, K. Subramaniam of HBCSE made a presentation titled "Symbols and language in school algebra: theoretical approaches," on the meaning aspect of symbols and Frege's theory of meaning was used to analyze the situation in algebra. Various other theories of understanding mathematical symbols like Sfard's and Tall's process-object duality were discussed. He connected these further with understanding structure of expressions and examples from classroom situation. The presentation by Rakhi Banerjee of HBCSE dealt with her doctoral research project aimed at exploring the feasibility of teaching beginning students structure of arithmetic expressions and use of the procedural and structural knowledge developed in arithmetic in the context of algebra.

Later in the course of the main conference Marc de Vries conducted a satellite workshop on the *"Philosophy of technology for research in technology education"*. De Vries gave the participants a glimpse of the nature and functions of philosophy of technology. Though scheduled over two evenings, at the end of academically intense days, most participants chose the workshop over the distractions of Goa. De Vries argued for the critical and analytical function of philosophy to provide a language that avoids fruitless discussions of technology's relationship to science. He outlined two approaches to the philosophy of technology: the engineering or "internal" and the humanities or "external" philosophy of technology. He showed that philosophy of technology provides a conceptual basis for developing a curriculum in technology education as well as for teaching technology as a school subject. By extension, it forms the foundation for research in technology education. Several issues related to the ontological, epistemological, methodological and metaphysical aspects of technology were addressed.

After an introduction to the taxonomy of objects, de Vries explained the physical and functional nature of technical artefacts using examples. The philosophy of actions (plans) and the nature of the design problem and process as well as the modes of being (modalities) of artifacts were discussed and a framework for a more precise ontology of technological objects was presented along with an outline of the nature of technological systems. Addressing epistemological issues, de Vries pointed out that technological knowledge could not be seen as "justified true belief" for several reasons. For one, it does not cover technological norms, know-how and drawings. He discussed the prescriptive and functional dimensions of technological knowledge and levels of normativity and concluded that acceptance was a more appropriate criterion than belief for technological knowledge. The engineering sciences were shown to have a hybrid character - that of science (abstract, universal, idealised, simple) as well as technology (concrete, unique/specific, real, complex).

De Vries discussed the methodological issues in technology beginning with the known approaches to methodology in the development of science. After a brief summary of the positivist, hypothetico-deductive (Popperian) and the paradigmatic (Kuhnian) approaches, de Vries focused on Lakatos's theoretical programme, and Feyerabend's eclectic approaches, which fit the development of engineering science more than any others. He summarised the views of several philosophers, in the humanities tradition (external) covering almost a century, and discussed the postmodernist breakdown of boundaries between human and machine and between virtual and real. Through several pictures and video clips, he highlighted aesthetics and ethics as important dimensions of the philosophy of technology. He ended with the examples of the Challenger and Bhopal tragedies as grim reminders of the ethical dilemmas in technology.

The two units of the book

The review talks were scheduled in the plenary sessions in the first half of the day. Each of the seven review talks was around an hour in duration, including the discussion sessions. The papers based on these talks are organised in this book into two units. The participants' comments and questions along with the speaker's responses are presented at the end of each paper in a section titled "Discussion on the presentation". The first unit, titled "**Basic Cognitive Sciences**" contains three chapters. This unit focuses on the underlying theoretical notions about knowledge, thought and learning that are drawn from cognitive science, a field that derives inputs from psychology, neuroscience, linguistics, anthropology, sociology, information processing and education. The cognitive science paradigm in education is at present the dominant one, having been fruitful in terms of opening up areas for research. While this paradigm is generating a lot of research in the area of students' understanding of science, its translation into actual classroom practice has been limited. The cognitive paradigm has emphasized the understanding processes of ***STM*** and has given rise to new meta-cognitive tools such as concept maps, context maps, advanced organizers, etc. for mapping the knowledge of an individual and for understanding the differences that exist between a beginner and an expert in the field. Knowing these differences helps in the design and modification of instructional material and teaching that can lead to more meaningful understanding.

The three chapters in this unit are based on models of cognition, knowledge representation and the relation between language and cognition. In the opening chapter, *Layers in the fabric of mind: a critical review of cognitive ontogeny,* G. Nagarjuna, tracks the major ideas in cognitive science in the last three decades. Nagarjuna's perspective on cognitive development encompasses epistemology, AI and the biological basis of the mind. He demonstrates the inconsistencies and problems in the explanations of human cognition provided by the dominant trends in cognitive science in terms of being; modular/non-modular, domain specific/domain general, biological/ cultural, and tries to bridge these divisions. Nagarjuna presents a four-layered model of cognitive ontogeny; biological, subjective, inter-subjective and formal. The direction of cognitive development is in terms of the transfer of implicit procedural knowledge to different forms of explicit conceptual knowledge. Science in this explanation is a part of layer 4, the formal layer, and understanding this structure can crucially affect science education.

In chapter 2, *The challenge of knowledge soup*, John Sowa considers the problem of knowledge representation and reviews the historical approaches to this problem suggested by Aristotle, Leibnitz and Kant, which have led to modern day attempts at implementation using computers. The biggest obstacle to such implementation is the immense complexity with which humans are constantly faced and which they do handle successfully in comparison to computers. Sowa suggests that the key to this problem lies in three types of reasoning that have so far been neglected by systems using deductive reasoning exclusively. These are the methods of induction, abduction and analogy which have led to the development of systems using case-based reasoning. “Analogy engines” using concept graphs may capture some of the complexities of the real world.

In the third chapter on *Language and cognition* Probal Dasgupta highlights current work on the role of language and cognition in the practice and teaching of science. He addresses the work of Vygotsky, on the way image-based preconcepts must turn into the abstractions operative in society’s adult, industrial economy as the adolescent schoolchild grows into a serious knower. The present survey of where the field stands is built around Sarukkai’s demonstration that formal abstract concepts are embedded in multiple semiotic systems.

The second unit on **“Science, Technology and Mathematics Education”** ***(STME)*** has four chapters. While the first unit is aimed at providing an overview of the developments in the forefront of learning and cognition, the second unit is directly connected to educational researches and the trends in research in science, technology and mathematics education. Research in science, technology and mathematics education is of relatively recent origin; yet it has begun to contribute to the content of textbooks and classroom practices. Over the last 30 years there has been a significant development and expansion of research in the field of science education. The field has met various structural criteria of established fields, such as, academic recognition, research journals and conferences, research centers and training and professional associations.

Three of the chapters in this unit provide a review of the trends in ***STME*** research around the world. In the Indian context, reviews of research studies in science education have appeared in the reports based on the national surveys of research in education. Carried out periodically, these surveys provide the statistics related to research areas and analyses of the observed trends and indicate the areas requiring further attention. The *Fourth Survey of Research in Education,* (Ganguli and Vashista, 1991)[1], covering a period of 14 years from 1974 to 1988, reports only a few researches in science education by Indian researchers (101 studies in 14 years, seven studies a year).

The *Fifth Survey of Research in Education* reported 61 studies during the period, 1988-1992 (Vaidya, 1997)[2]. The areas of research identified by this survey were environmental studies, curriculum, syllabus and textbook, learning science and models of teaching, teaching strategies, outcomes of science education (scientific temper, attitudes, skills and interests), correlates of achievements in science, educational technology, and others. According to Vaidya, the research frontiers that needed to be traversed were in history and philosophy of science and policy studies in science education.

A more recent survey of educational research in science education in India spanning the period 1993-2000, recorded over a period of eight years a total of 120 studies, which was double that in the earlier period (from 61 to 120). The annual average had increased from 12 to 15 (Chunawala, forthcoming)[3]. Yet, the final tally of studies is miniscule particularly in the light of existing and increasing growth in the number of schools, colleges,

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[1] Ganguli, D. and Vashistha, V.C. (1991). Research in science education: a trend report, in M.B. Buch (Ed) *Fourth Survey of Research in Education.* New Delhi: NCERT.
[2] Vaidya, N. (1997). Science education, the *Fifth Survey of Research in Education.* (Ed) New Delhi: NCERT.
[3] Chunawala, S. (forthcoming).Trend report on research in science education, *VIth Survey of Educational Research in India*, Nagaraju, C.S. (Ed) New Delhi, NCERT.

universities and institutions with large numbers of school and university teachers, teacher-educators, researchers and other academic staff who are involved in science education in India. The paucity of research stands in stark contrast to the frequent reforms, policy tussles and ideological battles that are continually played out in the field of Indian education.

To learn of the status of research in science, technology and mathematics education in other countries, the keynote speakers were requested to present an account of the research in areas of their specialization. While all the speakers were given the same brief, the presentations varied. David Treagust (Chapter 4) gave a succinct but comprehensive summary of the trends in science education research supported by detailed statistics. The slides of his presentation can be viewed at *http://www.hbcse.tifr.res.in/episteme1/themes/sci_edu_rsh*.

Treagust organized the trends around four aspects that have defined science education research over three decades. One of these aspects is the increasing professional research activities and internationalization of science education research. This is seen through an increase in English language publications and also an increase in the range of scholars involved in science education research. Another aspect is the concern for more relevant science education, and inclusivity, with a focus on understanding the reasons for the failure of the 'science for all' movement. The third aspect highlighted by Treagust is the diversity in the types of research in science education, from large scale national and international assessment programs to small scale studies in individual classrooms by the concerned teacher. This diversity is reflected in topics such as studies of the status of science teaching, the impact of technology on teaching, concerns about scientific literacy and research interests in science education. Lastly, Treagust reviewed the influence of science education research on policy and practice.

Kaye Stacey (Chapter 5) chose to focus on beginning algebra in order to illustrate some broad trends in mathematics education research. Stacey holds that the field of mathematics education is so large that it is essential to zoom in on a few issues of interest to gain a deeper understanding. She focuses on the active field of algebra education research and interestingly uses the methodology of case-study, with an in-depth analysis of algebra education, drawing parallels to mathematics education. Her overview of mathematics education brings out the interconnections and sharing of methodologies between mathematics education and other areas. It highlights the universal versus particularistic divide in the nature of findings in mathematics education research and the role of external and internal factors that influence trends in algebra education research as well as in other areas of mathematics education. Stacey's powerpoint presentation is available at *http://www.hbcse.tifr.res.in/episteme1/sch*.

Technology is a relatively new entrant in ***STME*** and ***STME*** research. Marc J. de Vries (Chapter 6) provided a unique perspective by using the concept of "didactics" or "systematic and scientific reflection on teaching practice" to analyze the articles published in the International Journal of Technology and Design Education (Vol 4-10, 1994-2000). De Vries remarks on the gap that exists between the interests of teachers and those of researchers in the area of technology education. The topics reported by teachers as relevant for their work are rarely addressed by research. Later in the paper he elaborates on the need to bring closer the research in the area of technology education to the practical needs of teachers. De Vries proposes an interesting model for this collaboration, analogous to the interaction that occurs in technology development between engineers, designers and customers or end-user. De Vries identifies the "hot topics" in technology education research; these are, design and problem solving, values and attitudes of teachers and pupils and presentations on the national curriculum. The presence of only a few contributions to the journal from Asian or African countries (< than 8%) and the need to enhance internationalism in the scope of publications in the field was a concern put forward by de Vries. It is a pleasure to report that the international linkages developed as a result of epiSTEME-1 have led to the possibility of more publications from the less represented regions.

In the last chapter Michael R. Matthews examines *the impact of idealist and relativist philosophies of science on contemporary science education research.* According to him, there is a need to develop curricula and educational materials with historical, philosophical and sociological perspectives in mind and to assess the presence of these perspectives in the existing materials. He points out that science education research is influenced by several philosophies of science, such as Positivism or Kuhnianism, and recently by constructivism (post Kuhnian idealist and relativist philosophies) which are naively and uncritically adopted by science educationists. He assesses the impact of these latter philosophical positions while quoting from a recent book on science education by Peter Fensham (2004).

He suggests that science education researchers (with their background in science or teaching) tend to be inadequately prepared, and only a rare few have formal training in psychology, sociology, history or philosophy. These inadequacies of science educationists according to Matthews have led to an uncritical acceptance of the idealist and relativist positions in science education research. He points to the debate over the terms *misconceptions* and *alternative conceptions* and suggests that the latter leads to research towards multi-science, as seen in multiculturalism, feminism and queerism. He concludes with an analysis that paints a grim picture of the progress in science education research. Matthews' perspective is sobering; yet it is fitting at this point to return to the earlier chapters, which illustrate how ***STME*** research has not only broadened our knowledge in a phenomenological sense, but has over time fed into theories of cognitive science to deepen our understanding of learning and pedagogy. We hope that the *epiSTEME* series of conferences will support the developments in the field.

Jayashree Ramadas & Sugra Chunawala
Editors

Unit 1

Basic Cognitive Sciences

Layers in the Fabric of Mind: A Critical Review of Cognitive Ontogeny

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Introduction

Cognitive science, particularly in the last three decades has witnessed several creative moments and innovative proposals on the nature of mind, naturalized epistemology, cognitive development, biological roots of cognition, and an attempt to understand what it is to be distinctively human, scientific, theoretical, and socio-cultural. Encouraging leads to the underlying biological roots of cognition also came from neuro-physiological investigations as well as theoretical biology. Cognitive architectures based on information processing approaches are gaining strength and becoming popular and getting somewhat closer to being accepted as the received view on the subject.

This multi-disciplinary discourse, along the way, not only reenacted several traditional philosophical positions, but also exhibited considerable innovation in rephrasing the traditional questions seemingly guided by a huge corpus of scientific findings from AI, physiology and pathology, and ingenious experiments on cognitive agents (both non-human and human subjects, including infants in cribs). While taking note of the developments, I wish to identify some conceptual and foundational problems in the dominant trends of the current cognitive science, and describe a picture of ontogenic layers that seems to represent the human cognitive phenomena. Given this vast multi-disciplinary canvas, a single essay cannot do justice in critically reviewing the area. I will therefore focus here on what I consider the most fundamental issue that has a bearing on the foundations of not only cognitive science, but also science education. As an epistemologist, I will dwell on issues closer to naturalized epistemology and architecture of mind than on empirical cognitive psychology.

The fundamental cognitive transition

The focus in this essay is on metasystem transitions[1]: from biologically rooted procedural knowledge to socially rooted declarative knowledge. Another fundamental transition, from folklore to science, will be alluded to while drawing the picture of the layers in the fabric of mind towards the end.

Why is the transition from procedural knowledge to declarative knowledge important? In the current literature, sensory-motor intelligence is mostly assimilated into what is generally known as *procedural knowledge*, as against *declarative knowledge* (Mandler, 2004). During cognitive development a child undergoes the transition from a modular, unconscious, non-verbal stage to non-modular, conscious, conceptual and verbal declarative knowledge. Since we do not begin with a display of verbal declarative knowledge at birth, but develop it eventually, even nativists

[1] The term "metasystem transition" coined by Valentin Turchin of the Principia Cybernetica Project (Turchin, 1977), whose focus is to study the major evolutionary transitions from microcosmic systems to the most complex social systems.

must account for this transition, though, strictly speaking, they are not developmentalists in their temperament. The problem, therefore, is as fundamental as the transition from non-living matter to living matter.

Piaget's model of cognitive development aptly identifies this problem as the focus of the transition from the first stage to the second. He mentions that sensory-motor operations provide the early *schemes* for developing the corresponding concepts (*schemas*) associated to the schemes (Piaget, 1970). In his model, cognitive agents act on objects, and this action is essential for learning. In this sense each subject *constructs* by acting on experience. Piaget made a strict connection between motor competence and conceptual competence. Though he underestimated infants' cognitive abilities, and considered the sensory-motor stage pre-conceptual, his studies continue to be relevant till date, for his identification of the problem is arguably correct. Subsequent studies on infants showed that such a stage may not be more than a few months after birth, while nativists argued that conceptual knowledge and consciousness are innate (Carey and Gelman, 1991). In a recent work, Jean Mandler, based on the work of several other researchers, provides an account of how wrong Piaget was, in assuming that infants during the first stage do not have declarative knowledge. Mandler argues, that both sensory-motor competence and conceptual competence develop almost at the same time and this happens very early, as early as six months after birth (Mandler, 2004).

Karmiloff-Smith in *Beyond Modularity* describes her theory of *representational redescription*, where she tries to reconcile Fodor's nativist model (Fodor, 1983) with Piaget's developmental model (Piaget, 1968). During the process of representational redescription, *implicit* procedural knowledge transforms into *explicit* declarative conceptual knowledge by a process of re-encoding (Karmiloff-Smith, 1995). In *Origins of the Modern Mind*, Merlin Donald narrates with detailed substantiation the evolution of modern humans from Apes. He convincingly demonstrates the transition from the more primitive procedural to *episodic* memory, which in turn, over several thousand years, transitions into more recent and peculiarly human *externalized* memory, with the intermediary mimetic and mythical stages (Donald, 1991). Though Donald is not talking about ontogeny, but phylogeny, the order of the transitions provides important clues to the possible ways a child might develop into an externalized social being.[2] Peter Gärdenfors in his recent work *How Homo became Sapiens* agrees with Donald and adds further weight to the *externalization* hypothesis, underlining how a process of detachment could help in the transition, as well as in characterizing human cognition (Gärdenfors, 2003). Keeping in view Vygotsky's emphasis on the role of the social character of the human mind (Vygotsky, 1978), and Wittgenstein's strong argument against private language, and in support of the essentially social nature of language and thought (Wittgenstein, 1953), leads us to expect very strong social and culturally rooted accounts of the human mind. We may not be able to accept these apparently incompatible views, unless we can reconcile them by employing a sound conceptual base. In this essay I move towards such a reconciliation. If developmental psychologists' are correct in stating that during early ontogeny implicit knowledge metamorphoses into explicit knowledge, Wittgenstein's argument of impossibility of private language comes into trouble. Though Wittgenstein's arguments were intended against the empiricist epistemology, the same argument can be cast against developmentalists.

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[2] No strict recapitulation of phylogeny in ontogeny is really possible, particularly due to the force of enculturation process as soon as the baby is born.

While it is possible to discern subtle differences between the various positions mentioned above, what comes home is that, to understand the nature of human cognition, it is important to understand the relation between the hardwired, implicit, inaccessible, procedural knowledge rooted in *neuro-sensory motor mechanisms* on the one hand and explicit, verbal, symbolic, accessible, public, conceptual, declarative knowledge rooted in *socio-cultural mechanisms* on the other. Even though a nativist like Fodor did not believe in the developmental view of cognition, he correctly identified that the harder problem is to understand the relation between the modular and the non-modular components of the mind (Fodor, 1983; Fodor, 2000).

It is important to note that I am making an over generalization when I am clustering a large set of descriptions of the phase before and after the transition, in the above passage. Such a grouping is not strictly justifiable. We may discern subtle differences among them. The clustered description however will help us to broadly confine to the domain of discourse that is the focus of this essay.

The engaging problem therefore is either to understand the functional *relation* between modular and non-modular aspects of mind, as a nativist would like us to say, or the *transition* from procedural knowledge to declarative knowledge, as developmentalists would want us to say. I tend more towards the developmentalists, though I hope to see a reconciliation, as Karmiloff-Smith did, and to grapple with the transition problem. Either way, it is clear that this is a non-trivial problem in cognitive science, and a solution to this problem will have serious implications in understanding human cognition.

In what follows, I will identify the conceptual problems with the influential modularity model of mind. We shall see that one of the essential characters of modules, namely informational encapsulation, is not only inessential, it ties a knot at a crucial place blocking the solution to the problem of understanding the formation of concepts from percepts (nodes of procedural knowledge). Subsequently I propose that concept formation takes place by *modulation of modules* leading to cross-representations, which were otherwise precluded by encapsulation. It must be noted that the argument is not against modular architecture, but against a variety of an architecture that prevents interaction among modules. This is followed by a brief argument demonstrating that a module without modularization, i.e. without developmental history, is impossible. Finally the emerging picture of cognitive development is drawn in the form of the layers in the fabric of mind, with a brief statement of the possible implications.

Modularity

Jean Piaget's theory of cognitive development is today considered to be a domain general account. His theory proposed a general mechanism in the form of *assimilation* and *accommodation* of experience based on genetically endowed potential schemes. For every cognitive task—perception, concept formation, arithmetic, language, space and time, geometry etc.—Piaget applied more or less the same pattern of analysis, and in this sense his account is domain-general. Recent studies however seem to suggest that such an across-the-board model cannot account for the observed differences in performance on the cognitive tasks from each domain (Carey and Gelman, 1991, Hirschfeld and Gelman, 1994). Thus, Piaget's domain-generality and stage theory were as observed in the previous section, seriously questioned.

In an intellectual atmosphere where behaviorism and empiricism were belittled, Noam Chomsky's nativism took firm ground among several practitioners in cognitive science. Chomsky questioned the developmental views of language, and argued that highly specialized inborn mechanisms called modules exist for grammar, logic, and other subcomponents of language processing, visual system, facial recognition etc. (Chomsky, 1988). Jerry Fodor extended this line of thinking and provided a foundation by characterizing a theory of modules in his famous *Modularity of Mind* (Fodor, 1983).

Fodor proposed that the mind is constituted of peripheral (perceptual), domain-specific, informationally encapsulated, dissociable, functional sub-systems that are mandatory, swift, and involuntary processing units, wholly determined by evolutionarily selected genetic endowment. However, the high-level central cognitive systems that are involved in belief, creativity, reasoning etc., are according to Fodor, amodular and non-encapsulated (Fodor, 1983; Fodor, 2000). In this model, the mind consists of several input subsystems producing swift *thoughtless* outputs. Interestingly Fodor included language also as an output of a module. While Fodor argued that the outputs are processed by non-modular central processing which works relatively slowly and *thoughtfully*, Tooby, Pinker, Sperber and Carruthers, argued that every faculty of mind is modular, aka massively modular (Cosmides and Tooby, 1994; Pinker, 1997; Sperber, 1994; Carruthers, 2005). However there is no clear consensus on what modularity means. For example, Carruther argues that some of the Fodorian specifications of modules, such as proprietary transducers, shallow outputs, domain specificity, fast processing and innateness, are not necessary, whereas modules have to be "isolable function-specific processing systems, whose operations are mandatory, which are associated with specific neural structures, and whose internal operations may be both encapsulated from the remainder of cognition and inaccessible to it." (Carruthers, 2005) The differences in characterizing modules is not so relevant for the issue at hand, except for encapsulation and domain specificity. We will return to a discussion of this in the next section.

Evidence for modularity comes from neurophysiological cases where several patients displayed loss of a *faculty* independent of others, due to partial damages in the brain. Modularity, being a computationally amenable property, attracted also those who took a computational view of cognition. Fodor[3] and Penrose[4] argued, though their arguments have different grounds, that higher faculties of mind cannot be assimilated in a computational framework.

Modularity, as a general feature, is commonly seen in biological organization at all levels of complexity. There is greater consensus that an

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[3] Fodor argues that computational theory of mind cannot answer global inferences like *abduction*, which require embedding in a *non-local* aspects of a mental representation such as a theory, while normal inferences are embedded in *local* aspects of a mental representation such as a syntax (Fodor, 2000). I think his argument is *asymmetrical*, since in local inference he takes syntactical aspect of mental representation, while in global inference he takes *semantic* aspect of representation, and not the syntax of the theory.

[4] Penrose argued in *The Emperor's New Mind* that artificial intelligence cannot solve the problem of consciousness, since Gödel's theorem, which sets a limit to what a Turing's computer can do, proves the impossibility of AI (Penrose, 1989). In a ater work, *Shadows of the Mind*, he argued that classical physics cannot address the consciousness problem, while quantum physics can(Penrose, 1994). Based on Hameroff's findings of microtubules, which form a scaffolding for a cell constituting cytoskeleton, Penrose hypothesizes that they can form a basis for the complex mental operations where, at Planck-scale, quantum functions collapse to generate

organism is gradually and hierarchically constructed out of several subsystems (Simon, 1962). This therefore is taken as an argument in favor of massive modularity. The possibility of transplanting some subsystems by artificial ones, is also a stronger evidence in favor of modular architecture in biology. However, all of biological organs are not directly related to what we normally call cognitively functional organs, for example heart. Sense organs (as input subsystems) are not so different from other biological organs and organ systems, because each of them have a domain specific function to perform and they work independently of each other. Therefore, what seems to be missing in this characterization is something that makes some of them cognitive, while keeping others *merely* non-cognitive biological subsystems. Extending this, we may also ask: Are there some special subsystems that are responsible for the distinctively human cognition? The main contender for the special human module is language. However, it is not very clear how without any difference in genetic makeup, say between a chimp and a human being, a biological system begins to display language behavior. Therefore, what makes a subsystem cognitive and what makes human cognition so different are still open questions.

Another argument in favor of modularity stems from evolutionary assumptions. Slow, non-modular, domain general processing would not be selected since they are not evolutionarily advantageous, and would not have evolved. General processing systems may not even behave consistently and would not give reliable results. Only swifter automatic subsystems would have been naturally selected during the course of phylogeny (Cosmides and Tooby, 1994). This argument goes against Anderson who argues that there would not have been enough time to evolve so many special modules, for human evolution has relatively a very short history

(Anderson, 1983). Most of the higher cognitive abilities seen in human beings have several things in common. Thus, a single change responsible for a general architecture may have resulted in the modern human mind.[5] The fact that there is almost a complete match, between the genetic code of Apes and human beings, supports general architecture.

When we look at the apparent differences between other beings and humans, encephalization[6] and lateralization of hemispheres with analytic left and synthetic right side, dexterous erect posture standing on two feet, are the striking biological differences, while language and social culture are the striking behavioral differences. The problem is to understand what differences determine what, and whether biological differences determine the socio-cultural, or vice versa. It is also important to note that unitary or modular theories are possible among biological as well as socio-cultural accounts.

In the following sections, I will propose a way of bridging these apparent divisions: modular and non-modular, domain specific and domain general, biological and cultural. It is also important to note that unitary or modular theories are possible among biological as well as socio-cultural accounts. I suggest that there exists a mechanism of *modulating* the modules, which eventually generates the higher and peculiarly human cognitive abilities.

[5] See (Donald, 1991) for a comprehensive comparison of modular versus unitary models of cognition.

[6] Encephalization is the increase in the relative size of the neocortex. Size of the brain of human beings is the largest (about three times that of the nearest primates) in relation to the rest of the body with about double the number of neurons. The large size is attributed to the increased size of the neocortex (cerebral cortex) which contains three fourths of the neurons in the human brain, which are organized into the two hemispheres.

This mechanism transforms the implicit into explicit, and this is the fundamental cognitive transition. This mechanism is recursive and is capable of generating new complex modules, which in turn get dissolved by modulation and cross-representation, generating complex layers of cognition.

Modulation of modules: Dissolving encapsulation

Informational encapsulation (insulation), inaccessibility of internal data and processing details, is proposed as a defining feature of a cognitive module. Without this feature nothing significant can be said about modularity (Fodor, 2000). Why is this hypothesis significant for understanding cognitive phenomena? Why do the believers of this hypothesis think that it explains cognition, and which aspect of cognition? What happens if an input subsystem is not encapsulated?

So much of data, we assume, must be generated by several of our input subsystems, particularly the sense organs (transducers). If our consciousness attends to each bit and processes such information *deliberately*, the processing of even a snapshot of all the *chunks* generated in a moment will take a long time. It is very unlikely that such a processing is happening. Our consciousness selects and attends to one chunk here and another chunk there, but cannot possibly process all the chunks and process. The assumption that the modules must be processing automatically and swiftly without 'thinking' and without the intervention of any other subsystem or central system seems therefore legitimate.

This is followed by another assumption that though the internal details of how the information is processed is not available, the output produced by them is available to the central system. Though this approach does eliminate a lot of processing details, the generated output of the modules at each moment is not small either. Also our consciousness does not seem to be attending to every chunk of the output. But by assuming that there exists an access to the output since it is not encoded in a proprietary format, we create a situation whereby when we wish we can attend to it. But, since we do not seem to be taking into account all of the accessible chunks, there seems to be another layer of 'encapsulation' or some other unknown mechanism, but at this step unlike in the first step of encapsulation, the data is not encoded in a proprietary format. However, we still need an explanation about how we can attend to one among the bundle of chunks at any given moment. The problem therefore does not disappear by supposing informationally encapsulated modules. By assuming that the information processing takes place by an inborn evolutionarily developed mechanism, we are completely insulating ourselves to see the most fundamental problem of cognitive science (by enclosing the problem in a capsule, and then worry about why the problem is not getting solved). This I think is the problem.

Do we theoretically need encapsulation? What purpose does this serve? One may argue, as Fodor does, that the concept was invoked to explain the mandatory and independent nature of certain perceptual results. The Müller-Lyer illusion, for example, is experienced despite our knowing that the two horizontal lines are of the same length (See Figure 1). The explanation given is that another subsystem or central system which 'knows' that the lines are of the same length cannot influence the input subsystem to perceive differently, because the input subsystem is encapsulated. Perception of illusion is therefore mandatory. There are alternative explanations to illusions that do not use the notion of encapsulation.

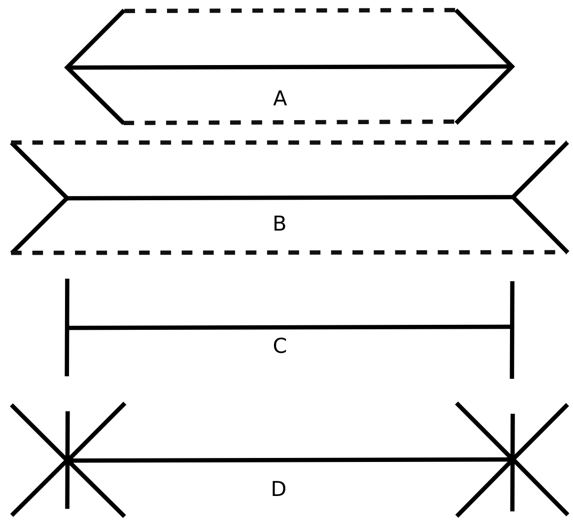

Figure 1: Resolving the Muller-Lyer Illusion by modulation: translating the lines A, B, and C producing D not only demonstrates the equality of length, but also that appearances can be modulated.

Piaget employs the idea of relative centration (Piaget, 1969), and a very recent analysis offers a theory that explains various classes of optical illusions by proposing that noise causes bias leading to alteration in appearances (Fermüller and Malm, 2004). The illusion can also be resolved by assuming that there exists a genetic bias for shapes than for lines, or that it is *easier* to see shapes rather than lines. The assumption of informational encapsulation or proprietary databases seems unnecessary for explaining illusions.

Appearances can be deceptive as is well known. But how do we resolve them as deceptions is an issue that we should look at. When we do that, we will realize that the resolution of deceptions (and other perceptual illusions) happens by *modulating* our perceptual field. By modulation I mean modifying the effects of perception by altering certain conditions keeping certain other conditions constant. If our perceptual field can be modulated, then how can we say that there is encapsulation?

We can bring the lines A and B together, as shown in Figure 1 and see that they are equal in length, or we can bring another line C and compare the lines by measuring. But the very act of measurement involves modulating our appearances, by moving and matching the lines or bringing an yardstick like C. Though *we may not be able to alter the way our input subsystems work, we can change the conditions under which the object appears*. It is by *doing* so, which I call modulation, we resolve appearances, not merely the deceptive kind, but all.

I am not arguing that appearances are not mandatory, they indeed are. The point I am making is that the appearances being mandatory cannot generate knowledge without modulation. Collecting all appearances (chunks) would not constitute knowledge. Only the modulable part of the incoming information is perceivable. Modulation makes perception possible by introducing the necessary bias. This possibly also explains how *attention* is realizable. Knowledge is generated by an alteration of input and therefore the output. But *given the same conditions of input plus modulation, the subsystem must generate the same output*. This is the only assumption required of modules. The internal mechanism is also of no consequence, it can be an artificial mechanical system, or a natural biological system, or one can be transplanted by the other, so long as the above condition is met.[7] This is another way of saying that modules are sensitive to specific

[7] Researchers at the University of Wisconsin-Madison developed a tongue stimulating device that can be used for making the blind *see* (Sampaio et al., 2001). This possibility vindicates the flexibility of representation mechanism of our mind, and there is no one unique way of making an input subsystem.

input, which is domain specificity. We don't need any other notion such as informational encapsulation or proprietary databases to explain cognition. Subsystems are required to be modulatable and domain specific (by virtue of sensitivity of input systems to an aspect of environment), apply Occam's Razor to every other notion.

I will now connect modulation to concept formation, and argue that unmodulated appearances don't generate knowledge, that is concepts. I will argue that even rudimentary conceptual knowledge cannot be properly accounted if modules are encapsulated. However, it is mandatory that modules must be domain specific. We should not confuse implicit with inaccessible. Different subsystems interact with each other, and control each other. It is unnecessary to bring in a central control system, when control can be explained without it. That the mind is some kind of central processing unit, with privileged access to the output of all the modules, is a myth. We should replace that picture with *cellularity* of mind. In this alternative picture, all the subsystems, including the 'central' nervous system, interact with each other to produce a conscious cognitive loop.[8]

Modulation and concept generation

Let each input subsystem produce output in whatever format. Let us suppose that each subsystem is domain specific, meaning it is specific only to a kind of input and ignores others. Let us call each output thus produced a dimension. Each input subsystem thus produces a domain specific output as 'sound dimension', 'light dimension', etc. Now let us suppose a cognitive

[8] Please see my argument that a conscious cognitive loop cannot be made without bringing in the motor subsystem (Nagarjuna G., 2005b).

agent that has only one input subsystem, therefore generates only one dimension. However sophisticated be the subsystem, as long as it is domain specific, such an agent with only one input system can not generate any bit of information. Why? Because, such a perceptual space is *blind*.[9] It is like an undifferentiated ether. Information is a result of *differentiated difference*, which comes only by *interference* of another dimension. When two or more dimensions *cross* with each other, either concurrently or serially, a logical mark is possible in the undifferentiated space, for recognition needs an identifiable mark. This is very similar to the way a point is obtained by crossing two lines. It seems therefore impossible to think of individuating any *differentiated difference* without *cross-representations*.

Let us look at the computational theory of vision proposed by Marr. He proposes quite a few *modular* devices, each of which detect motion, edge, surface texture, etc. The resulting *vision* is a coordination of these modules. To generate a chunk of vision, so to speak, we need quite a few dimensions (Marr, 1983). There seems to be sufficient cross representation in this so as to generate useful information.[10] Each chunk of vision is already informationally very complex, since it comes with notions like space, position, shape, size, color, edge, motion, etc.

Assuming that each dimension comes to us from an independent module, and that information is impinging on our mental 'screen', we may think that the story of perception ends. But it doesn't. We may be able to see

[9] My allusion that perceptual space is blind may remind readers of the Kantian aphorism, that perceptions without conceptions are blind, and conceptions without perceptions are empty. Though insightful, my purpose here is to break this circle, and not depend on it.

[10] Fodor thinks that this provides confirmational basis for modularity (Fodor, 1983).

changes in the screen, but how do we know what causes (constrains) each of these changes? Mere cross-representation is not enough, since we will never know if there is a cross, if it is invariant. We need to introduce a mechanism to control (modulate) the crossing too. Karmiloff-Smith's theory that representational redescription happens by re-encoding cannot be the answer, though the line of argument is correct, because it begs the question. We still need to search for the mechanism of re-encoding.

I am proposing that this happens by *modulation of modules* which introduces the required differentiation of *cross-representations*.[11] Modulation of dimensions is a process where a cognitive agent introduces differences in some dimensions by keeping certain other things constant in the perceptual space. What I am suggesting is that the cognitive agent to begin with *consciously* performs certain operations that alter the perceptual space in a controlled way. For example, we move our eye muscles to focus once on the window pane, and once on the distant trunk of the tree in order to perceive the depth. Once used to it, we do this unconsciously, but the fact that this can be done consciously explains why there is no encapsulation. The motor input system can affect the visual field. Since this operation is deliberate, we could be certain that the differences in the appearance are constrained by controlled motion. This way, the difference gets differentiated. I propose that *differentiation of difference* is the foundation of all conscious cognition, which happens by modulation. Differentiation

[11] Though modulation of cross-representation is stated to be the basis, I believe there exists another fundamental kind of modulation of states, a set of cross-representations, and the mapping between them leading to *across*-representations. While the former becomes the basis for analytic reason, the latter for analogical reason. Analogical reason is as fundamental as analytic, and should not be neglected. John Sowa's contribution on "Knowledge Soup" in this volume does to some extent fill this gap, though he argues analogies to be more primitive than analytic.

of difference produces the required cross-representation. One can see much of what I am proposing implicitly in Marr's theory, but what is missing is the requirement of *modulatory action by the agent* which introduces the constraint required for differentiation.

To see the causal connection between differences in appearances, we need no higher form of inference like abduction, as Fodor thought. The constraints for inference are already available to the subject, since modulation is initiated by the subject, making the inference fast and direct, and therefore avoiding the frame problem. The assumption of proprietary database also serves the purpose of avoiding the frame problem.[12] Since in the current proposal no proprietary database is assumed, one may think that the frame problem might arise. However, as mentioned above, modulation itself provides the required constraint for faster and direct inference. If we assume a loop between a sensory subsystem and a modulation system, we do not need expensive computation to solve the problem.[13]

If this line of argument is valid, one thing is clear: knowledge is generated due to modulation of cross-representations, a sort of multi-dimensional/ inter-modular interference or interaction. This mechanism then may be either innate or learned. I believe the potential to modulate is innate, while the context for modulation is culture. What seems the likely basis for concept formation is: loose physiological coupling, characterized by interactive and functional relations between different domain specific subsystems, rather than encapsulated modular structures.

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[12] See the discussion by Weiskopf on modularity and frame problem (Weiskopf, 2002).

[13] The nature of this loop is discussed in (Nagarjuna G., 2005b), where voluntary muscles controlled by the central nervous system form a loop with sensory subsystems to generate the required self-modulation.

Consequently, we, human beings, are not compelled to take what the input subsystems have to offer. We have the ability to differentiate the differences caused by the input systems. It is this *freedom* that makes us *reflect*, and thus begets our thought. Other animals may also be getting deceived by appearances, but due to our freedom to modulate our perceptual field we resolve several of those deceptions. I started this section with a discussion of an illusion, let us end it with another illustration.

In Figure 2 the horizontal line in A appears smaller than the vertical line though they are of the same length. That our perceptual modules have no bias to vertical lines becomes clearer if we see the case of E, where the vertical looks smaller than the horizontal. Interestingly the lines in situations B, C, and D are seen as equal. The situation in D is more interesting, since both the lines look smaller than the line F, though all the figures are constructed by using a line of the same length as F. D is produced by rotating B but looks smaller than B. Our judgments about the length are based on modulation by translation or rotation of the lines. We break the mandatory appearances by altering not only the relationship between the modulatable components of the figure, but also our relationship with them. Though the appearance depends on the context, the context itself is modulable. In fact we can make the illusion appear and disappear by doing so, and also understand the conditions under which the illusion happens. Appearance is mandatory only because the context is similar and not due to any encapsulation.[14] There are neither proprietary databases nor private encodings. Sensory subsystems are domain specific, i.e., sensitive only to a specific input.

[14] The encapsulation hypothesis is not even required for nativism, for nativism is logically possible without assuming it. I haven't come across any argument from a nativist that nativism and encapsulation must go hand in hand.

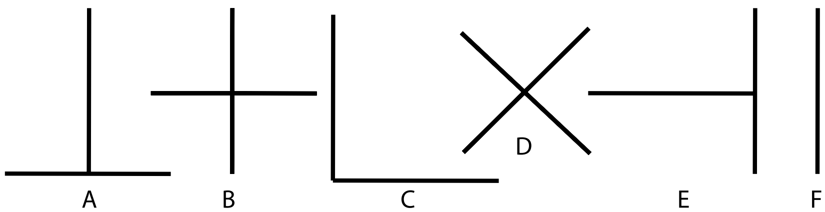

Figure 2: Modulation resolves the deceptive appearances

Layers in the fabric of mind

I argued above that domain specific modules can be modulated, and this process has the potential to explain concept formation. In the process the implicit procedural ‘knowledge’ transforms into explicit declarative knowledge. By demonstrating that modules can be modulated by the agent’s actions, modules become Piaget’s *schemes*. This reconciliation of nativism and Piaget is different from that of Karmiloff-Smith’s. In her account, modules are the product of post-natal development. I am suggesting that input subsystems are hardwired and biologically given. However, to remain consistent with a developmental account, they are also products of a developmental process. But this process is embryological, and therefore purely biological. Biological ontogeny in the form of maturation continues even after birth, and this process may enhance the sensory-motor potential, but remains biological nevertheless. This developmental process remains the bedrock for other layers in the story, forming **Layer 1**: biological ontogeny.

Cognitive development essentially begins after birth. A new-born child is like a cognitive ‘ovum’, it gets ‘fertilized’ by experience of both the cultural world and the ‘natural’ world. This onsets the development of the **Layer 2**: *subjective cognitive ontogeny*. This process also continues to develop, though reaches maturation (meaning modularization) very fast. The character of representations that are produced at this stage are *cross-representations*. These representations are a result of the subjective cognitive ontogeny, and remain *procedural*. This corresponds to the nature of knowledge generated during the sensory-motor stage of Piaget, and the percepts of Mandler. Let me clarify here that this account is not a stage theory, it is the character of knowledge generated that corresponds to the Piaget’s sensory-motor stage and not the stage to the Layer 2. One important difference is that these layers continue to exist and develop, and they don’t stop or transform into another at any time. Subjective experience doesn’t cease when we tend to become inter-subjective or objective. This layer produces the mandatory appearances that sometimes result in the illusions we discussed in the previous section. Most of animal cognition remains at this stage, since the process that generates the other cognitive layers, modulation of cross-representations, doesn’t seem to be available to them. Karmiloff-Smith’s representational redescription, for the same reason is also not available to them. This corresponds to the ‘implicit’ level in Karmiloff-Smith’s theory.

The first two layers now become the foundation for the **Layer 3**: *inter-subjective cognitive ontogeny*. In some of the higher cognitive agents, particularly human beings, the implicit procedural knowledge transits to explicit declarative knowledge by modulation of cross-representations, leading to representational redescription, generating explicit representations. This is what we called the fundamental cognitive transition. The cognitive agent for the first time in cognitive ontogeny begins to develop a *detachment* between *sign* and *signifier*, where the former is publicly (inter-subjectively) accessible. This is when percepts become concepts. This layer is sufficiently complex and amenable for further layers within. Karmiloff-Smith distinguishes three 'levels' of this Layer 3: Explicit 1 (E1), Explicit 2 (E2), and Explicit 3 (E3). E1 is explicit but not accessible to consciousness, E2 is explicit and accessible to consciousness, and E3 is accessible, conscious, and verbally reportable (Karmiloff-Smith, 1995).

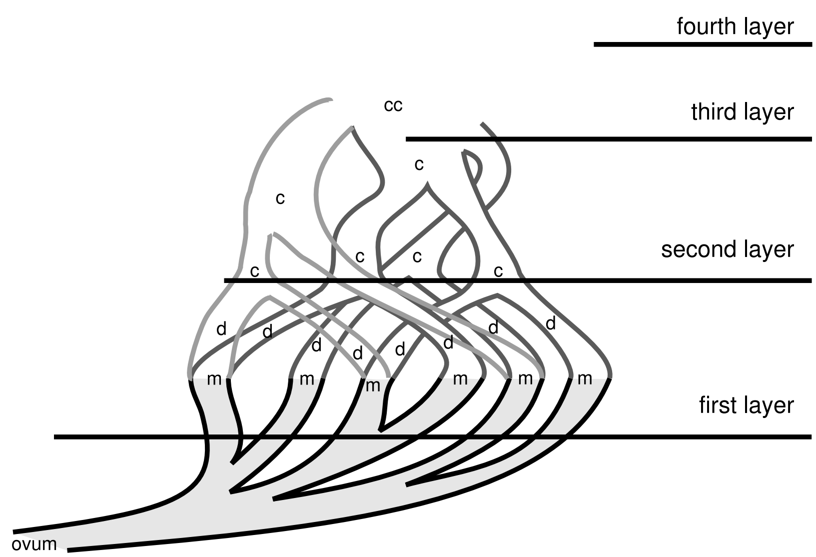

Figure 3: Layers in the Fabric of Mind: A diagrammatic representation of the layered view. Undifferentiated ovum develops by embryogenesis into a modular differentiated organism. Each module (m) generates a domain specific dimension (d) the dimensions cross with each other by modulation to produce cross-representations (c) which upon differentiation of difference produce a unitary conscious cognition (cc). The arrows indicate roughly that the lower layer continues to develop and exist while the other layers develop on top.

Though there is no strict matching with our account, Donald's three stages during phylogeny of modern humans also fall in Layer 3. He identifies during phylogeny a stage of episodic representations to begin with, leading to semantic externalized representations, mediated by mimetic and mythic layers (Donald, 1991). It is during this process that the language module, the most unique human character, develops. This view is unlike that of Chomsky and Fodor, who argued for innate language modules. While I disagree with them on this, language is mostly 'hereditary' in the sense that is almost entirely due to cultural inheritance. Behaviorally, a lot of play, practice and enculturation (training) are responsible for this layer to develop. Socialization and language go hand in hand, for they are not possible without each other. It seems therefore plausible to hypothesize that representational redescription is an *essential* mechanism in producing *external* memory space helping to enhance much needed memory capacity for storing cultural heritage, and also for *detached* processing of information. Thought and imagination too are due to *detached* processing of representations, but happening in the subjective space—internal modulations. Layer 3 is too rich to capture in a paragraph. To sum up, what happens in this layer is that implicit procedural representations transform into explicit declarative knowledge by 'rewriting'. This process is the hub of all eventual higher cognitive functions. Layer 3 has all the necessary paraphernalia for developing the peculiar socio-cultural human life and culminates in the production of folklore.

The three layers thus formed become the foundation for the exclusively human **Layer 4**: *formal cognitive ontogeny*. This layer develops by transformation from folklore of Layer 3. Declarative knowledge of folklore in this new layer gets redescribed in formal operations. In this layer, no assumptions remain implicit while knowledge of Layer 3 depends a great deal on implicit and subjectively available experience. Here all the knowledge is stated as a declarative representation. During formal cognitive ontogeny, concepts are artificially and operationally *represented* without a direct bearing on experience. They may be idealizations of Layer 3 concepts. The concepts that form the basis of formal knowledge may or may not have observational basis, but they do have an operational basis. By operational I mean rule based construction based on definitions. Since definitions state the conditions explicitly, confining to a constructed conceptual space, this makes these new constructions completely *detached* from perceptual experience. Scientific knowledge, for example, is an *explicitly constructed* form of knowledge in the sense that the rules of construction are overtly specified. This form of possible world construction creates an idealized description of the actual world that describes indirectly (mediated by models) the phenomenal world. They 'touch' the real world here and there. By this I mean the logical space of possible worlds extends beyond the actual space of the real world. This constructed form of knowledge results into formal, mathematical and scientific knowledge. By formal I do not mean only mathematical or algebraic. A piece of knowledge becomes formal, when any representation-the symbols, the rules of combining them, relations between them, etc., are fully made explicit. This requires the knowledge to be re-represented in an entirely artificial language. One may see what I am saying comes closer to some branches of science like physics, but the view may be rejected for other sciences such as biology, economics and social science. The possibility of reconstructing an artificial language by using mostly available vocabulary from folklore, makes us see the essentially formal nature of the latter sciences. Just as the folklore notions of force, energy and work do not just extend into the scientific notions by the same names, the folklore notions of "heart" and "species" do not extend into biological space. If this view, that science is not part of the Layer 3, is true, then it will have serious implications for science education. Most science education practices assume that science is an extension of common sense. The view I am arguing for demands an epistemic break from common sense. I do not have space to provide a complete argument here. Please see "From Folklore to Science" for a complete statement of this position (Nagarjuna, 2005a), where a demarcation criterion in the form of conditions that make the transition from folklore to science is presented.

Before I close this section, a few lines on the nature of the layers would be relevant. What is the relationship between the layers? The top layers depend on the bottom layers. This dependence is substantial. Just as the living layer of the world depends on the physical non-living layer, the formal layer depends on the folk layer, and this folk layer depends on the biological. Layers on top, once developed, do not replace the bottom layers, they only cover them. This view is different from that of Thomas Kuhn who argued that revolutions replace the former body of knowledge (Kuhn, 1970). Kuhn's view is the most outlandish, and unfortunately the most influential, view from an otherwise careful historian of science. I argued (Nagarjuna, 1994) that Kuhn confuses psychological (ontogenic) replacement that *may* happen in a believer with historical (phylogenetic) replacement. Top layers emerge due to changes in the functional relationship of the underlying ontological layer. Substantially there exists only one ontological world, the distinctions of the layers are methodological helping us to theorize. Thus this position can be characterized as ontological monism and epistemological pluralism.

A question also arises naturally regarding the relation of the layered view with that of Piaget's stage theory. Stage view suggests that the cognitive being transits from one kind to another. Layered view suggests that the being develops an additional layer without losing the earlier base. Metaphorically it is more like a few threads of the fabric of the bottom layers *escape* to form the latter layers. As shown in the Figure 3, the layers in the fabric of mind, for each *thread* of development, it is possible to provide a stage theory, but not for the cognitive being as a whole.

Implications

The layered view of cognitive phenomena presented above, if plausible, indicates a few fundamental changes in the way we view ourselves. The view suggests that the direction of human cognitive development involves the transformation of implicit procedural knowledge into different forms of explicit conceptual knowledge. The mechanisms that play a role in such transformations are not genetic in the classical sense, but arise from our cultural or social inheritance. The bundle of peculiarly human characteristics are strongly tied with the social fabric of human life rather than arising from the genetic, neuro-physiological domain. Evidence is gradually accumulating to suggest that the larger size of human brain (encephalization) is mostly to do with this new-found socio-cultural context. The fact that the genetic and anatomical differences between apes and humans is so marginal indicates that this problem cannot be answered by gene and brain-centric viewpoints. In (Nagarjuna, 2005b) I proposed a hypothesis to explain the genesis of conscious cognition. The fundamental cognitive transition, explained above, is argued to be due to the emancipation of biologically driven modular operations, resulting in conscious cognitive operations, including those related to the social and symbolic life of humans. During this process the inaccessible knowledge begins to expose itself through modulations, and this process itself generates the symbolic life of higher animals.

While arguing against the behaviorist model we tended to be excessively 'inward' looking in our search to describe human nature. If my arguments have any weight, we should be looking mostly at what is publicly accessible to understand what is peculiarly human, and how they transform the private into public. This will have implications for Wittgenstein's private language argument, where he argued against the possibility of private representations. Neuro-physiology can inform us about the manner of encoding episodic memory, but possibly not of semantic memory, an essential form of human cognition. It is highly likely that semantic memory is stored exclusively in the externalized public socio-cultural mind-space. However, procedural and episodic memory form the basis for socio-cultural semantic memory. Scientific knowledge is necessarily and undoubtedly located in the inter-subjective space. Scientists tend to have 'gut' reactions against socio-cultural foundations of science. But, I think, this does not by any means make it less objective, since externalizing by re-encoding is the only means of making private subjective knowledge public and potentially objective. By interpreting Wittgenstein's argument as applying only to semantic memory and not episodic or procedural, I suggest a transformation mechanism in terms of modulation and representational redescription, which explains one of the mechanisms involved in learning and discovery.

Lastly, a remark on implications of this view for science education. Most leading cognitive psychologists (e.g., Alison Gopnik) believe in a strong working hypothesis called "theory-theory". According to this view no knowledge worth the name can be non-theoretical, and the basic mechanism (or methodology) of knowledge formation and evaluation happens by theory-change, and this mechanism is universal. By demonstrating that even infants in the crib are little theoreticians, they argue that the mechanism that makes us know the world is the same as that which makes science. If our account of Layer 4 is correct, the theory-theory view comes into question. While I agree that there are general cognitive mechanisms (or methodologies), it is necessary to make certain finer distinctions which weaken the strong form of theory-theory. First of all, we need to make a clear distinction between conceptual and analogical: the former is a result of cross-representation while the latter is a result of *'across' representation* drawing in similarities across domains based mostly on relational knowledge. Further, all theories are not of the same nature, particularly the model driven, counter-intuitive scientific theories. The latter theories are artificially constructed, explicitly rule governed and hence not in continuation of folk-lore. The character of theories in folklore and formal science must carefully be distinguished. If we think that science is not an extension of common-sense, our approach to formal science education needs to change.

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Discussion on the presentation

Comment: The private language argument of Wittgenstein is that a person cannot have a language that only that person can understand. However, babies do have their own private language, and so also do artists who have only a few persons whom they can vibe with, and who are perhaps the crucibles of creativity, hence there is a secret initiation even among teacher and students. This aspect of language needs careful attention.

Speaker: Wittgenstein considers only explicit knowledge, while analysing the private language argument. That is how he concludes that private language is not possible. Today we have enough evidence to suppose that implicit knowledge exists in undeclared procedural form. Such knowledge is related more to episodic or procedural memory and not to semantic memory. The explicit form of rule following language belongs to the semantic memory. I therefore do not think Wittgenstein's argument against private language is valid for all forms of memory, or one must say the scope of his argument is limited only to semantic memory . If this line of argument is valid, the observations that children or poets or creative engagement of any agent having a private language can be accounted for by interpreting that their experiences are encoded at some stage of implicit knowledge. The main difference between a child and a poet will be that the child lives with the implicit knowledge while the poet makes a creative effort to bring the implicit experience into a shareable public sphere by re-encoding the representations. Given this developmental framework, the distinction between private and public, or implicit and explicit is only a difference of degree and not of kind.

Query: You have presented a comprehensive understanding of cognition. In this context are instincts and reflexes that are part of corneal modules numeric? If yes, and the cross representation is essential for memory then take a counter example: Suppose a man goes blind and possibly his memory has developed a concept of an object from the cross representation of sound and vision. Since he has gone blind, and you hold an object towards him, from sounds he could adapt to it. Can you explain this cross representation as beyond vision and sound?

Speaker: Reply to the first question; Instincts and reflexes according to the model proposed, form part of not only implicit knowledge, but also of the genetically (innately) determined. In this context I will render memory, similar to knowledge. The second question appears tricky, If I understood it correctly, the question is to know what happens to the theory of cross-representations when a normal person becomes blind. Firstly, recently found evidence shows that blind people can see through sufficiently sensitive areas of skin's tactile receptors by differentially stimulating them according to the picture generated through a camera (See Sampaio, E., Maris, S., and Bach-y-Rita, P. (2001).) This shows that there is nothing 'visual' about photoreceptors except providing information about the external world. If an image can be obtained by touch, and we already know that an image can be obtained also from sound (e.g. in bats), then what is required for a cross-representation to happen is the possibility for at least two crossing dimensions. This is consistent with the evidences pouring about the flexible architecture of our nervous system. This flexibility will enable agents to adapt to the new situation.

Comment: The presentation is consistent with the approach of Charles Saunders Pierce based on semiotics. Also a recent book "The symbolic species: The Co-Evolution of Language and the Brain" by Terrence W. Deacon presents interesting insights of neuro-science and anthropology focussing on the co-evolution of language and the brain and this seems similar to your work.

Speaker: If the developmental approaches similar to Piaget or Karmiloff-Smith are shown to be consistent with those of C.S. Peirce, it will be both historically and philosophically very insightful and instructive to the development of cognitive science. This connection, however, is not surprising because, both approaches are comprehensive, reconciliatory in nature and are not narrow in the manner of the behaviorists, positivists or nativists.

Query: You proposed epistemological pluralism and ontological monism, would you like to test it; review the course of science whether its non-inductive/non-rational, how would you review it in view of science, i.e., representational and rediscriptive form of process and in that process you move from implicit to explicit and then you talk of episodic sequentialism; when poets have remote interconnections they try to present realities as they are and how the inter connections are. In your explanation you spoke of layers like embryogenesis, social, conceptual layers etc. What constitutes these layers; being a scientist do you have any biases towards these layers, with the scientific layer on top?

Speaker: The empirical part of the presentation is that as the cognitive development progresses and as the agent moves from one layer to the other there is progressive increase of explicit knowledge. Such a claim is testable. I do not think, a philosophical position like ontological monism and epistemological pluralism are proper empirical claims.

Query: The problem with Karmiloff Smith's theory of representational redescription is the concept of redescription. Even if you do not subscribe to a radical situationist theory of knowledge, the concept of redescription is one wherein what you are describing is already described somewhere.

Speaker: First of all, in a developmental perspective all descriptions are on one scale, differing only in degree and not in kind. When a description is getting redescribed, it becomes more explicit. Each redescription is another re-encoding, therefore the model is internally consistent. The model allows the possibility of explicit knowledge becoming implicit, which is nothing but modularization. I do not think there is any serious conceptual problems in Karmiloff-Smith's theory of representational redescription.

The Challenge of Knowledge Soup

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Human knowledge is a process of approximation. In the focus of experience, there is comparative clarity. But the discrimination of this clarity leads into the penumbral background. There are always questions left over. The problem is to discriminate exactly what we know vaguely.

Alfred North Whitehead, Essays in Science and Philosophy.

Abstract

People have a natural desire to organize, classify, label, and define the things, events, and patterns of their daily lives. But their best-laid plans are overwhelmed by the inevitable change, growth, innovation, progress, evolution, diversity, and entropy. These rapid changes, which create difficulties for people, are far more disruptive for the fragile databases and knowledge bases in computer systems. The term *knowledge soup* better characterizes the fluid, dynamically changing nature of the information that people learn, reason about, act upon, and communicate. This article addresses the complexity of the knowledge soup, the problems it poses for computer systems, and the methods for managing it. The most important requirement for any intelligent system is flexibility in accommodating and making sense of the knowledge soup.

Issues in knowledge representation

The reasoning ability of the human brain is unlike anything implemented in computer systems. A five-dollar pocket calculator can outperform an human on long division, but many tasks that are easy for people and other animals are surprisingly difficult for computers. Robots can assemble precisely machined parts with far greater accuracy than any human, but no robot can build a bird nest from scattered twigs and straw or wash irregularly shaped pots, pans, and dishes the way people do. For recognizing irregular patterns, the perceptual abilities of birds and mammals surpass the fastest supercomputers. The rules of chess are defined with mathematical precision, but the computers of the 1960s were not fast enough to analyze chess patterns at the level of a novice. Not until 1997 did the world chess champion lose to a supercomputer supplemented with special hardware designed to represent chess patterns. The rules and moves of the oriental game of Go are even simpler than chess, but no computer can play Go beyond the novice level. The difference between chess and Go lies in the nature of the patterns: chess combinations can be analyzed in depth by the brute force of a supercomputer, but Go requires the ability to perceive visual patterns formed by dozens of stones placed on a 19×19 board.

The nature of the knowledge stored in people's heads has major implications for both education and artificial intelligence. Both fields organize knowledge in teachable modules that are axiomatized in logic, presented in textbooks, and stored in well structured databases and knowledge bases. A systematic organization makes knowledge easier to teach and to implement in computer systems. But as every student learns upon entering the workforce, "book learning" is limited by the inevitable complexities, exceptions, and ambiguities of engineering, business, politics, and life. Although precise definitions and specifications are essential for solving problems in mathematics, science, and engineering, most problems aren't well defined. As Hamlet observed, "There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy."

The knowledge soup poses a major challenge to any system of organizing knowledge for ease of learning by people or ease of programming in computers. Section 2 of this article surveys attempts to develop such systems. Section 3 discusses the inevitable exceptions and disruptions that cause well organized systems to degenerate into knowledge soup. As a framework for accommodating the complexity, managing it, and even taking advantage of it, Section 4 presents some issues in cognitive science and the semiotics of Charles Sanders Peirce. His insights into both the power and the limitations of logic suggest methods for addressing the challenge and designing more adaptable and ultimately more human-like systems. The concluding Section 5 puts the issues in perspective and proposes directions for future research.

Attempts to organize and formalize knowledge

For over two thousand years, Aristotle's categories and his system of syllogisms for reasoning about the categories were the most highly developed system of logic and ontology. The syllogisms are rules of reasoning based on four sentence patterns, each of which relates one category in the subject to another category in the predicate:

1. *Universal affirmative.* Every employee is human.

2. *Particular affirmative.* Some employees are customers.
3. *Universal negative.* No employee is a competitor.
4. *Particular negative.* Some customers are not employees.

The two affirmative patterns are the basis for inheriting properties from more general categories to more specialized ones. The two negative patterns state constraints that rule out combinations that are not meaningful or permissible.

In the third century AD, Porphyry drew the first known tree diagram for organizing Aristotle's categories according to the method of definition by *genus and differentiae*. Figure 1 shows a version translated from the Summulae Logicales by Peter of Spain (1239). It shows that the category Body is defined as the category Substance with the differentia material, and Human is defined as Animal with the differentia rational. By following the path from the top, the category Human would inherit all the differentiae along the way: rational, sensitive, animate, material substance.

Similar tree diagrams are widely used today to represent hierarchies of concept types in modern knowledge representation languages. Although Aristotle's syllogisms are the oldest system of formal logic, they form the core of modern *description logics (DLs)*, such as OWL, which are often used for defining ontologies. OWL and other DLs add important features, such as numeric-valued functions, to Aristotle's monadic predicates. For many applications, however, the Aristotelian subset of logic serves as the framework that supports all the rest.

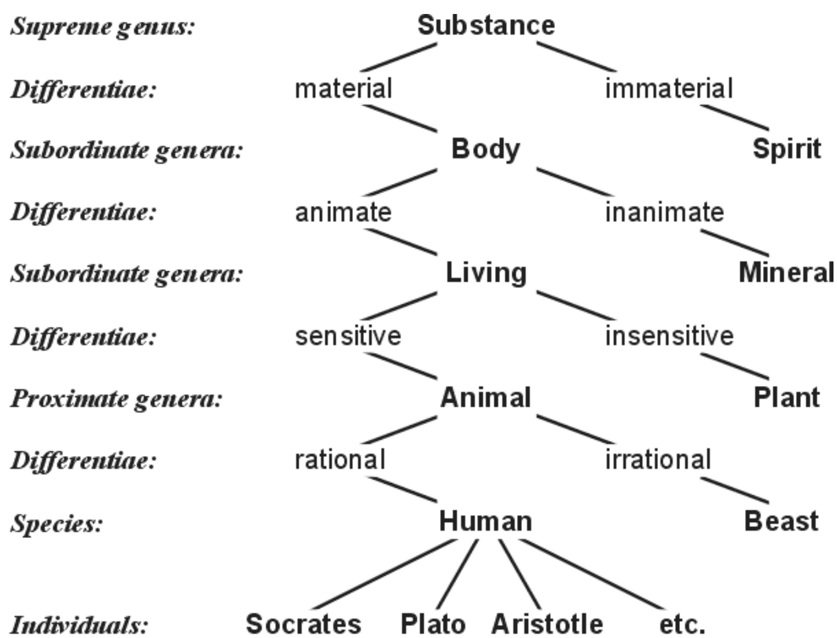

Figure 1: Tree of Porphyry

In the 17th century, Latin was losing its status as the common literary and scientific language of Europe. To avoid fragmentation in Babel of mutually unintelligible languages, various schemes were proposed for a universal language based on Aristotle's logic and categories. Scientists as renowned as Descartes, Mersenne, Boyle, Newton, and Leibniz devoted some attention to the project (Knowlson 1975). The idea was even satirized by Jonathan Swift as one of the projects at the grand academy of Laputa in *Gulliver's Travels*. In a scheme that resembled the sentence-generating machine in Laputa, Leibniz (1666) hoped to automate Aristotle's syllogisms by encoding the categories as integers:

> The only way to rectify our reasonings is to make them as tangible as those of the Mathematicians, so that we can find our error at a glance, and when there are disputes among persons, we can simply say: Let us calculate, without further ado, in order to see who is right.

Leibniz used prime numbers to encode primitive concepts and products of primes to encode compound concepts: if 2 represents Substance, 3 material, and 5 immaterial, the product 2×3 would represent Body and 2×5 would represent Spirit. A sentence of the form *Every human is animate* would be true if the number for *human* is divisible by the number for *animate*. This method works well for reasoning about affirmative propositions, but Leibniz never found a satisfactory method for handling negation. Although he abandoned his early work on the project, Leibniz (1705) still believed in the importance of developing a hierarchy of categories:

> The art of ranking things in genera and species is of no small importance and very much assists our judgment as well as our memory. You know how much it matters in botany, not to mention animals and other substances, or again moral and notional entities as some call them. Order largely depends on it, and many good authors write in such a way that their whole account could be divided and subdivided according to a procedure related to genera and species. This helps one not merely to retain things, but also to find them. And those who have laid out all sorts of notions under certain headings or categories have done something very useful.

In his *Critique of Pure Reason*, Immanuel Kant adopted Aristotle's logic, but he proposed a new table of twelve categories, which he claimed were more fundamental than Aristotle's. Although he started with a new choice of categories, Kant was no more successful than Leibniz in completing the grand scheme:

> If one has the original and primitive concepts, *it is easy* to add the derivative and subsidiary, and thus give a complete picture of the family tree of the pure understanding. Since at present, I am concerned not with the completeness of the system, but only with the principles to be followed, I leave this supplementary work for another occasion. It can *easily* be carried out with the aid of the ontological manuals.

Note the added italics: whenever a philosopher or a mathematician says that something is easy, that is a sure sign of difficulty. No one ever completed Kant's "supplementary work."

With the advent of computers, the production and dissemination of information was accelerated, but ironically, communication became more difficult. When product catalogs were printed on paper, an engineer could compare products from different vendors, even though they used different formats and terminology. But when everything is computerized, customer and vendor systems cannot interoperate unless their formats are identical. This problem was recognized as soon as the first database systems were interconnected in the 1970s. To enable data sharing by multiple applications, a *three-schema approach*, illustrated in Figure 2, was proposed as a standard for relating a common semantics to multiple formats (Tsichritzis and Klug 1978).

The three overlapping circles in Figure 2 represent the database, the application programs, and the user interface. At the center, the *conceptual schema* defines the ontology of the concepts as the users think of them and talk about them. The *physical schema* describes the internal formats of the data stored in the database, and the *external schema* defines the view of the data presented to the application programs. The contents of a database are uninterpreted character strings, such as "`Tom Smith`" and "`85437`". The conceptual schema specifies the *metadata* for interpreting the data as facts, such as "Employee Tom Smith has employee number 85437." It also states constraints and business rules, such as "Every employee must have a unique employee number."

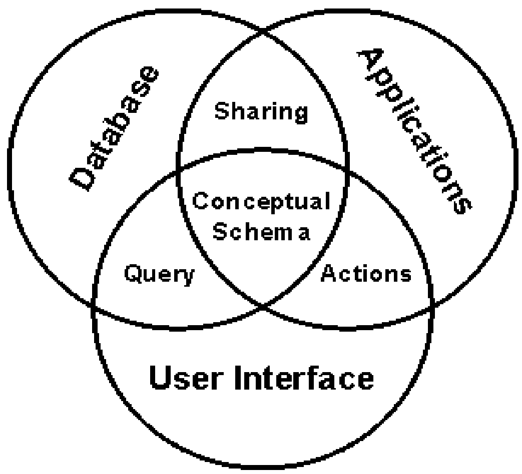

Figure 2: The ANSI-SPARC three-schema approach

The ANSI-SPARC report was intended as a basis for interoperable computer systems. All database vendors adopted the three-schema terminology, but they implemented it in incompatible ways. Over the next twenty years, various groups attempted to define standards for the *conceptual schema* and its mappings to databases and programming languages. Unfortunately, none of the vendors had a strong incentive to make their formats compatible with their competitors'. A few reports were produced, but no standards.

Meanwhile, the artificial intelligence community developed several large dictionaries and ontologies. Three of the largest were Cyc (Lenat 1995), WordNet (Miller 1995), and the Electronic Dictionary Research project (Yokoi 1995). In terms of the sheer amount of knowledge represented, Cyc is the largest with the most detailed axioms, and WordNet is the smallest and least detailed. WordNet, however, is the most widely used, largely because it is freely available over the Internet. For some purposes, the lack of detail in WordNet makes it more flexible, since it imposes fewer restrictions on how the definitions can be used.

The Cyc project, founded 1984 by Doug Lenat, illustrates the frustrations faced by AI researchers. The name comes from the stressed syllable of the word *encyclopedia* because its original goal was to encode the knowledge in the *Columbia Desk Encyclopedia*. As the project continued, the developers realized that the information in a typical encyclopedia is what people typically do not know. Much more important is the implicit knowledge everybody knows, but few people verbalize - what is often called *common sense*. The Cyc developers, however, seriously underestimated the amount of common knowledge required to understand a typical newspaper. After 20 years of elapsed time and 700 person-years of work at a cost of 70 million dollars, the Cyc project had encoded 600,000 concept types, defined by two million axioms, and organized in 6,000 microtheories.

As people mature, they seem to learn faster by building on their previously learned background knowledge: university students learn more information more quickly than high-school students, who in turn learn faster than elementary-school students. For that reason, Lenat hoped that a large knowledge base would enable Cyc to acquire new knowledge at an ever increasing rate. Unfortunately, Project Halo, a study funded by Paul Allen, the cofounder of Microsoft, suggested that the effort required to encode new knowledge in Cyc is about the same as in other systems with much smaller knowledge bases (Friedland et al. 2004).

For Project Halo, three groups were asked to represent the knowledge in a chemistry textbook: Cycorp, Ontoprise, and SRI International. The researchers in each group translated the selected pages from English, mathematics, and chemical formulas to the formats of their system. After the three groups had tested and debugged the new knowledge base, they were given questions from a freshman-level chemistry exam, which were based on the information in those pages. Each system was required to answer the questions (as translated to its own formats) and generate English-like explanations of the answers. Following are the results:

- The scores ranged from 40% to 47% correct.
- The average cost to encode the information was about $10,000 per page from the textbook.
- Despite its large knowledge base, Cyc had the lowest score, and it did not have any advantage over the other systems in the cost of encoding knowledge.

Although the three systems were able to generate English-like explanations, none of them was able to read and understand the original English from the textbook or the English questions on the exam.

Cyc represents the culmination of the Aristotelian approach. Its hierarchy of 600,000 concept types is the largest extension of the Tree of Porphyry ever implemented, and its automated reasoning is the fulfillment of Leibniz's dream. Although Cyc's categories are not based on Kant's, they are the closest realization of the "supplementary work" that Kant envisioned. Unfortunately, "ranking things in genera and species," as Leibniz said, has not proved to be profitable. The Cyc project has survived for over twenty years, but only with the infusion of large amounts of research funds. A few commercial applications of the Cyc technology have been modestly successful, but they have not generated enough revenue to support ongoing research and development, let alone provide any return on the original investment.

Knowledge soup

The major obstacle that Cyc or any similar project must address is the complexity of the knowledge soup — the heterogeneous, often inconsistent mixture that people have in their heads. Some of it may be represented in symbolic or propositional form, but much, if not most of it is stored in image-like forms. The soup may contain many small chunks, corresponding to the typical rules and facts in Cyc, and it may also contain large chunks that correspond to Cyc's microtheories. As in Cyc, the chunks should be internally consistent, but they may be inconsistent with one another.

The complexity does not arise from the way the human brain works or the way that natural languages express information. As Whitehead observed, it results from left-over questions lurking in "the penumbral background" and the difficulty of recognizing which ones are relevant to the "focus of experience":

- *Overgeneralizations.* Birds fly. But what about penguins? A day-old chick? A bird with a broken wing? A stuffed bird? A sleeping bird? A bird in a cage?

- *Abnormal conditions.* If you have a car, you can drive from New York to Boston. But what if the battery is dead? Your license has expired? There is a major snowstorm?
- *Incomplete definitions.* An oil well is a hole drilled in the ground that produces oil. But what about a dry hole? A hole that has been capped? A hole that used to produce oil? Are three holes linked to a single pipe one oil well or three?
- *Conflicting defaults.* Quakers are pacifists, and Republicans are not. But what about Richard Nixon, who was both a Quaker and a Republican? Was he or was he not a pacifist?
- *Unanticipated applications.* The parts of the human body are described in anatomy books. But is hair a part of the body? Hair implants? A wig? A wig made from a person's own hair? A hair in a braid that has broken off from its root? Fingernails? Plastic fingernail extender? A skin graft? Artificial skin used for emergency patches? A band-aid? A bone implant? An artificial implant in a bone? A heart transplant? An artificial heart? An artificial leg? Teeth? Fillings in the teeth? A porcelain crown? False teeth? Braces? A corneal transplant? Contact lenses? Eyeglasses? A tattoo? Make-up? Clothes?

These exceptions and borderline cases result from the nature of the world, not from any defect in natural language. A logical predicate like bodyPart(x) would solve nothing, since hair and fingernails would raise the same questions as the English phrase *body part*. The discrepancy results from a mismatch of the continuous world with the discrete words of language or predicates of logic: all languages consist of discrete symbols organized in discrete syntactic patterns; the real world, however, contains an endless variety of things, events, forms, substances, gradations, changes, and continuous flows with imperceptible transitions from one to another. No language based on discrete words or symbols can ever capture the full complexity of a continuous system.

Even for knowledge that can be represented in discrete symbols, the enormous amount of detail makes it practically impossible to keep two independently designed databases or knowledge bases consistent. Most banks, for example, offer similar services, such as checking accounts, savings accounts, loans, and mortgages. Banks have always been able to interoperate in transferring funds from accounts in one to accounts in another. Yet when two banks merge, they never merge their accounts. Instead, they adopt one of two strategies:

1. Keep running both databases indefinitely, or
2. Close some or all accounts of one bank, and open new accounts in the database of the other bank.

There are too many poorly understood and incompletely documented details for any bank to risk catastrophic failure by merging independently developed databases.

The continuous gradations and open-ended range of exceptions make it impossible to give complete, precise definitions for any concepts that are learned through experience. Kant (1800) observed that artificial concepts invented by some person for some specific purpose are the only ones that can be defined completely:

> Since the synthesis of empirical concepts is not arbitrary but based on experience, and as such can never be complete (for in experience ever

> new characteristics of the concept can be discovered), empirical concepts cannot be defined.
>
> Thus only arbitrarily made concepts can be defined synthetically. Such definitions... could also be called *declarations*, since in them one declares one's thoughts or renders account of what one understands by a word. This is the case with *mathematicians*.

Kant's observation has been repeated with variations by philosophers from Heraclitus to the present. Two of the more recent statements are the principles of *family resemblance* by Ludwig Wittgenstein (1953) and *open texture* by Friedrich Waismann (1952):

- *Family resemblance*. Empirical concepts cannot be defined by a fixed set of necessary and sufficient conditions. Instead, they can only be defined by giving a series of examples and saying "These things and everything that resembles them are instances of the concept."

- *Open texture*. For any proposed definition of empirical concepts, new instances will arise that "obviously" belong to the category but are excluded by the definition.

These principles imply that all classifications are approximations. For any collection of concepts, new examples will inevitably arise that don't quite fit any of the existing categories. But deductive reasoning requires precise definitions, clearly stated axioms, and formal rules of inference.

Kant, Wittgenstein, and Waismann were philosophers who fully understood the power and limitations of logic. The mathematician and philosopher

Alfred North Whitehead, who was the senior author of the *Principia Mathematica*, one of the most comprehensive treatises on logic ever written, was even more explicit about its limitations. Following are some quotations from his last book, *Modes of Thought* (1938):

- "Both in science and in logic, you have only to develop your argument sufficiently, and sooner or later you are bound to arrive at a contradiction, either internally within the argument, or externally in its reference to fact."
- "The topic of every science is an abstraction from the full concrete happenings of nature. But every abstraction neglects the influx of the factors omitted into the factors retained."
- "The premises are conceived in the simplicity of their individual isolation. But there can be no logical test for the possibility that deductive procedure, leading to the elaboration of compositions, may introduce into relevance considerations from which the primitive notions of the topic have been abstracted."

Whitehead certainly believed that logic is important, but he also realized that it is only part of any comprehensive system of learning, reasoning, and acting in and upon the world. He summarized his position in one sentence: "We must be systematic, but we should keep our systems open." Logic is an excellent means for reasoning about well-defined knowledge, but by itself, logic cannot make poorly defined terms precise or determine if any relevant information is missing.

The complexities of the knowledge soup are just as troublesome whether knowledge is represented in logic or in natural languages. When the

Académie Française attempted to legislate the vocabulary and definitions of the French language, their efforts were undermined by uncontrollable developments: rapid growth of slang that is never sanctioned by the authorities, and wholesale borrowing of words from English, the world's fastest growing language. In Japan, the pace of innovation and borrowing has been so rapid that the older generation of Japanese can no longer read their daily newspapers.

Cognitive processing

Over the past two million years, evolutionary processes added the human ability to think in discrete words and syntactic patterns to an ape-like ability to integrate continuous geometrical information from the visual, tactile, auditory, and motor regions of the brain. The ape brain itself took about a hundred times longer to evolve from a fish-like stage, which in turn took several times longer to evolve from a worm-like ganglion. Figure 3 illustrates the evolutionary stages.

The cognitive systems of the animals at each level of Figure 3 build on and extend the capabilities of the earlier levels. The worms at the top have rudimentary sensory and motor mechanisms connected by ganglia with a small number of neurons. A neural net that connects stimulus to response with just a few intermediate layers might be an adequate model. The fish brain is tiny compared to the mammals, but it already has a complex structure that receives inputs from highly differentiated sensory mechanisms and sends outputs to just as differentiated muscular mechanisms, which support both delicate control and high-speed propulsion. Exactly how those mechanisms work is not known, but the neural evidence suggests a division into perceptual mechanisms for interpreting inputs and motor mechanisms for controlling action. Between perception and action there must also be some sort of cognitive processing that combines and relates new information from the senses with memories of earlier perceptions.

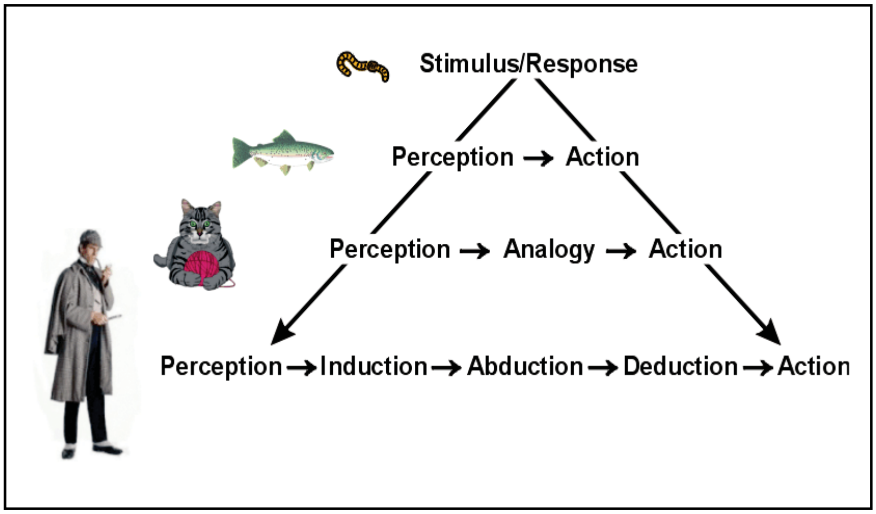

Figure 3: Evolution of Cognition

At the next level, mammals have a cerebral cortex with distinct *projection areas* for each of the sensory and motor systems. If the fish brain is already capable of sophisticated perception and motor control, the larger cortex must add something more. Figure 3 labels it *analogy* and symbolizes it by a cat playing with a ball of yarn that serves as a mouse analog. The human level is illustrated by a typical human, Sherlock Holmes, who is famous for his skills at induction, abduction, and deduction. Those reasoning skills, which Peirce analyzed in detail, may be characterized as specialized ways of using analogies, but they work seamlessly with the more primitive abilities.

Without language and logic, human society and civilization would still be at the level of the apes. Those animals are extremely intelligent, but they lack the ability to recognize and generate symbols. The neurophysiologist and anthropologist Terence Deacon (1997) noted that the slow evolution of the brain and vocal tract toward modern forms indicates that early hominids already had a rudimentary language, which gave individuals with larger brains and better speaking ability a competitive advantage. To distinguish human and animal communication, Deacon used Peirce's semiotic categories of *icon, index,* and *symbol* to classify the kinds of signs they could recognize and produce. He found that higher mammals easily recognize the first two kinds, icons and indexes, but only after lengthy training could a few talented chimpanzees learn to recognize symbolic expressions. Deacon concluded that if chimpanzees could make the semiotic transition from indexes to symbols, early hominids could. The evidence suggests that the transition to symbolic communication occurred about two million years ago with *homo habilis*. Once that transition had been made, language was possible, and the use of language promoted the co-evolution of both language and brain.

Logic is much broader than the mathematical version invented by Boole, Peirce, and Frege. It includes Aristotle's syllogisms, which are a stylized form of the reasoning expressed in ordinary language, but the only reasoning method supported by syllogisms is deduction, which is also the primary method used in Cyc and the Semantic Web. Peirce recognized that deduction is important, but he maintained that two other methods — induction and abduction — are equally important:

1. *Deduction.* Apply a general principle to infer some fact.
```
Given: Every bird flies. Tweety is a bird.
Infer: Tweety flies.
```

2. *Induction.* Assume a general principle that subsumes many facts.
   ```
   Given: Tweety, Polly, and Hooty are birds.
   Fred is a bat.
   Tweety, Polly, and Hooty fly. Fred flies.
   Assume: Every bird flies.
   ```
3. *Abduction.* Guess a new hypothesis that explains some fact.
   ```
   Given: Every bird flies. Tweety flies.
   Guess: Tweety is a bird.
   ```

These three methods of reasoning depend on the ability to use symbols. In deduction, the general term *every bird* is replaced by the name of a specific bird *Tweety*. Induction generalizes a property of multiple individuals — Tweety, Polly, and Hooty — to the category Bird, which subsumes all the instances. Abduction guesses the new proposition *Tweety is a bird* to explain one or more observations. According to Deacon's hypothesis that symbols are uniquely human, these three reasoning methods could not be used by nonhuman mammals, not even the apes.

According to Peirce (1902), "Besides these three types of reasoning there is a fourth, analogy, which combines the characters of the three, yet cannot be adequately represented as composite." Analogy is more primitive than logic because it does not require language or symbols. Its only prerequisite is *stimulus generalization* — the ability to recognize similar patterns of stimuli as signs of similar objects or events. In Peirce's terms, logical reasoning requires symbols, but analogical reasoning could also be performed on image-like signs called *icons*.

Analogical reasoning is general enough to derive the kinds of conclusions typical of a logic-based system that uses induction to derive rules followed by deduction to apply the rules. In AI systems, that method is called *case-*

based reasoning (Riesbeck and Schank 1989), but the principle was first stated by Ibn Taymiyya in his comparison of Aristotle's logic to the analogies used in legal reasoning (Hallaq 1993).

Ibn Taymiyya admitted that deduction in mathematics is certain. But in any empirical subject, general axioms can only be derived by induction, and induction must be guided by the same principles of evidence and relevance used in analogy. Figure 4 illustrates his argument: Deduction proceeds from a *theory* containing general axioms. But those axioms must have earlier been derived by induction with the same criteria used for analogy. The only difference is that induction produces a theory as intermediate result, which is then used in a subsequent process of deduction. By using analogy directly, legal reasoning dispenses with the intermediate theory and goes straight from cases to conclusion. If the theory and the analogy are based on the same evidence, they must lead to the same conclusions.

Note that the theory in Figure 4 requires some language or system of symbols for stating the axioms, but case-based reasoning (CBR) can be applied directly to image-like icons without any requirement for symbols as intermediaries. In legal reasoning, all the cases are described in symbols, but animals without language could apply analogical reasoning to cases recorded in imagery. Temple Grandin, an autistic woman who despite the odds managed to earn a PhD, gave a vivid description of her use of imagery (Grandin and Johnson 2004). She believes her image-based reasoning methods are of the same nature as the reasoning methods used by other mammals. She noted that her own reasoning tended to be very concrete, and she found it impossible to understand abstractions that could not be related to concrete images. She was able to do mathematics, but she thought of numbers as images, which she could visualize and manipulate.

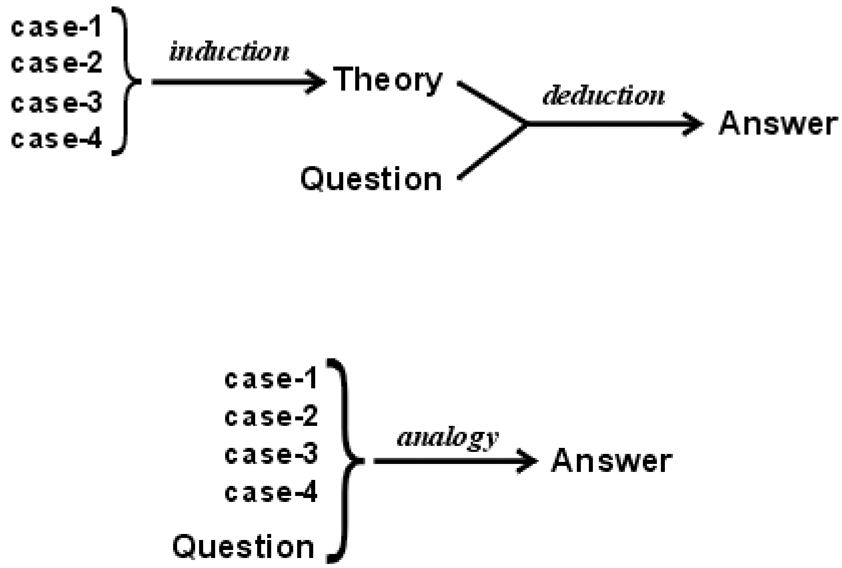

Figure 4: Comparison of logical and analogical reasoning

Whether the medium consists of words or images, the methods of CBR are the same: start with a question or goal Q about some current problem or situation P. By the methods of analogy, previously experienced cases that resemble P are recalled from long-term memory. When the cases in Figure 4 are recalled, they must be ranked according to their similarity or *semantic distance* to the current situation P. The case with greatest similarity to P (i.e., the smallest semantic distance) is considered the most relevant and the most likely to provide a suitable answer to the question Q. When a relevant case has been found, the aspect of the case that provides the information requested by Q is the predicted answer. If two or more cases have nearly equal relevance, they may or may not predict the same answer. If they do, that answer can be accepted with a high degree of confidence. If not, the answer is a disjunction of alternatives: Q_1 or Q_2. Psychologically, none of these operations depend on consciousness; in fact, the methods of measuring similarity or relevance are necessarily preconscious because they determine which images from long-term memory are introduced to consciousness.

As an application of CBR, the VivoMind Analogy Engine (Sowa and Majumdar 2003) was used to evaluate free-form answers to algebra word problems, which ranged in length from a short phrase to one or two sentences. Such texts are difficult to analyze correctly by computer, and even good teachers are not 100% correct in their evaluations. Two previous attempts had failed to provide a satisfactory solution:

- *Logic based.* One approach used a deductive method as described in Section 2. However, it required a sophisticated ontology and methods of knowledge representation that were unfamiliar to most high-school teachers.
- *Statistical.* Another was based on statistical methods commonly used for information retrieval. However, it could not distinguish correct answers from incorrect answers because they often used the same words, but in different word order.

The VivoMind method was short and direct: translate the English sentences or phrases to conceptual graphs (CGs); use VAE to compare them to previously evaluated answers; and report the teacher's evaluation for the answer that gave the closest match.

In terms of Figure 4, the cases were the student answers that had previously been evaluated by some teacher. For each evaluated answer, there was a teacher's response of the form "correct," "incorrect," or "partially correct with the following information missing." For any new case P, the question Q was a request for an evaluation. Unlike the logic-based or statistical approaches, the CBR method had an excellent success rate on cases for which VAE found a match with a small semantic distance. If VAE could not find a close match for some case or if two or more answers were equally close, VAE would send the case to a teacher, who would write a new evaluation. Then the new case with its associated evaluation would enlarge the set for future evaluations. After 30 or 40 cases had accumulated, a teacher's assistance was rarely needed to evaluate new cases. This example illustrates several points about analogical reasoning in general and case-based reasoning in particular:

1. Every case is stored in memory as a pattern of signs, but those signs need not be symbols. External stimuli are usually iconic or image-like; internal signs or feelings may be differentiated by their origin and strength, but they are indexical, not symbolic.
2. Some measure of semantic distance is necessary for determining which previous case P is the most relevant to the current goal or question Q.
3. Measuring semantic distance requires some basis for determining the relevance or preference for one pattern of signs over another, but the signs need not be symbolic. Semantic distance may be determined by similarities of icons or indexical references.
4. A hierarchical classification, similar to the Tree of Porphyry, would be useful for determining semantic distance, but the elements of the hierarchy need not be concepts, words, or other symbols. A

hierarchy of images could be determined by the perceptual mechanisms of stimulus generalization.

5. For any measure of semantic distance, the structure or geometry of the patterns is at least as important as the elements that occur in the patterns.

For symbolic patterns, such as linguistic sentences and stories, the relational structure and the types of concepts are equally relevant.

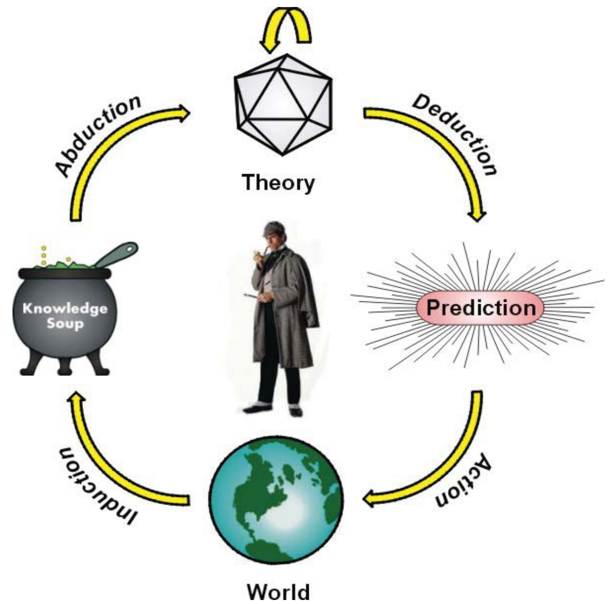

Figure 5: The Cycle of Pragmatism

A measure of semantic distance is essential for analogy, but it can also improve the logical methods of induction, deduction, and abduction. To illustrate the relationships, Figure 5 shows an agent who repeatedly carries out the stages of induction, abduction, deduction, and action. The arrow of induction indicates the accumulation of previously useful patterns in the knowledge soup. The crystal at the top symbolizes the elegant, but fragile theories that are constructed from chunks extracted from the soup by abduction. The arrow above the crystal indicates the process of belief revision, which uses repeated abductions to modify the theories. At the right is a prediction derived from a theory by deduction. That prediction leads to actions whose observable effects may confirm or refute the theory. Those observations are the basis for new inductions, and the cycle continues.

Of the three methods of logic, abduction is the only one that can introduce a truly novel idea. In Peirce's system, abduction is the replacement for Descartes's innate ideas and for Kant's synthetic *a priori* judgments. Abduction is the process of using some measure of semantic distance to select relevant chunks from the knowledge soup and assemble them in a novel combination. It can be performed at various levels of complexity:

- *Reuse*. Do an associative search for a previously used rule, pattern, or theory that can be applied to the current problem.

- *Revise*. Find a theory or fragment of a theory that approximately matches the problem at hand and apply the belief revision operators to adapt it to the current situation.

- *Combine*. Search for scattered fragments or *chunks* of knowledge and perform repeated steps of belief revision to combine them or modify them to form a theory appropriate to the current situation. If two theories are consistent with one another, their combination can be defined by a conjunction of the axioms of both. If their conjunction is inconsistent, several different consistent combinations may be extracted by choosing different axioms to delete in order to avoid contradictions.

All these processes may be used iteratively. After a hypothesis is formed by abduction, its implications must be tested against reality. If its implications are not confirmed, the hypothesis must be revised in another stage of abduction. In Peirce's logic of pragmatism, the free creations of thought generated by abduction are constrained at the two "gates" of perception and action:

> The elements of every concept enter into logical thought at the gate of perception and make their exit at the gate of purposive action; and whatever cannot show its passports at both those two gates is to be arrested as unauthorized by reason. (EP 2.241).

Note Peirce's word *elements*: abduction does not create totally new elements, but it can reassemble previously observed elements in novel combinations. Each combination defines a new concept, whose full meaning is determined by the totality of purposive actions it implies. As Peirce said, meanings grow as new information is received, new implications are derived, and new actions become possible.

In summary, deduction can be very useful when a theory is available, as in mathematics, science, and engineering. But analogy can be used when no theory exists, as in law, medicine, business, and everyday life. Even when logic is used, the methods of induction and abduction on the left side of Figure 5 are necessary for learning new knowledge and organizing it into the systematic theories required for deduction. Figure 5 suggests why Cyc or any other purely deductive system will always be limited: it addresses only the upper left part of the cycle. Today, computerized theorem provers are better at deduction than most human beings, but deduction is only 25% of the cycle. Instead of automating Sherlock Holmes, Cyc and other deductive systems require people with his level of expertise to write axioms at a cost of $10,000 to encode one page from a textbook. The methods of induction, abduction, and analogy are key to designing more robust systems, and good measures of semantic distance are key to analogy as well as all three methods of logic.

Directions for future research

Language understanding requires pattern recognition at every level from phonology and syntax to semantics and pragmatics. The sound patterns learned in infancy enable an adult to understand his or her native language in a noisy room while selectively attending to one of several simultaneous conversations. Although most syntactic patterns can be programmed as grammar rules, the enormous flexibility and novel collocations of ordinary language depend on semantic patterns, background knowledge, extralinguistic context, and even the speaker's and listener's familiarity with each other's interests, preferences, and habits. Even when the syntax and semantics of a sentence is correctly parsed, the listener must recognize the speaker's intentions and expectations and their implications in terms of the current situation. Any and every aspect of human knowledge and experience may be needed to understand any given sentence, and it must be accessible from long-term memory in just a few milliseconds. Furthermore, much if not most of the knowledge may be stored in nonlinguistic patterns of images derived from any sensory modality.

In a few short years, children learn to associate linguistic patterns with background knowledge in ways that no computer can match. The following sentence was spoken by Laura Limber at age 34 months:

> *When I was a little girl, I could go "geek, geek" like that;*
> *but now I can go "This is a chair."*

John Limber (1973) recorded Laura's utterances throughout her early years and analyzed her progress from simple to complex sentences. In this short passage, she combined subordinate and coordinate clauses, past tense contrasted with present, the modal auxiliaries *can* and *could*, the quotations "geek, geek" and "This is a chair," metalanguage about her own linguistic abilities, and parallel stylistic structure. Admittedly, Laura was a precocious child who probably benefited from the extra attention of her father's psychological studies, but children in all cultures master the most complex grammars with success rates that put computer learning systems to shame. The challenge of simulating that ability led the computer scientist Alan Perlis to remark "A year spent in artificial intelligence is enough to make one believe in God" (1982).

The despair expressed by Perlis afflicted many AI researchers. Terry Winograd, for example, called his first book *Understanding Natural Language* (1972) and his second book *Language as a Cognitive Process: Volume I, Syntax* (1983). But he abandoned the projected second volume on semantics when he realized that no existing semantic theory could explain how anyone, human or computer, could understand language. With his third book, coauthored with the philosopher Fernando Flores, Winograd (1986) switched to his later work on the design of human-computer interfaces. Winograd's shift in priorities is typical of much of the AI research over the past twenty years. Instead of language understanding, many people have turned to the simpler problems of text mining, information retrieval, and designing user interfaces.

One of the projects that is still pursuing a purely deductive approach is the Semantic Web (Berners-Lee et al. 2001). Its goals are similar to the goals of the ANSI-SPARC approach illustrated in Figure 2: support interoperability among independently developed computer applications. But instead of interoperability among multiple applications that use the same database, the Semantic Web is addressing the bigger problem of supporting interoperability among applications scattered anywhere across the World Wide Web. Unfortunately, current proposals for the Semantic Web are based on a subset of the Cyc logic with an ontology that is still a fraction of the size of Cyc. The only hope for any project with the scope of the Semantic Web is to address the full pragmatic cycle in Figure 5, with emphasis on the methods of induction and abduction on the left side of the cycle. With anything less, it's unlikely that thousands of ontologists scattered across the WWW using a weaker version of logic will be more successful than Cyc's tightly managed group located at a single site.

The central problem for any kind of reasoning is finding relevant information when needed. As Leibniz observed, a well-organized hierarchy "helps one not merely to retain things, but also to find them." But as this article has shown, the complexities of the world cause such systems to break down into knowledge soup. Humans and other animals have been successful in dealing with that soup because their brains have high-speed associative memories for finding relevant information as needed. To support such a memory in computer systems, Majumdar and Sowa (forthcoming) developed a method of *knowledge signatures*, which uses continuous numeric algorithms for encoding knowledge and finding relevant knowledge with the speed of an associative memory. This method enabled the VivoMind Analogy Engine to find analogies in time proportional to (N log N) instead of the older N-cubed algorithms. Such a method for finding relevant information can make a dramatic improvement in every method of reasoning, including induction, deduction, abduction, and analogy. More research is needed to develop tools and techniques to take advantage of these algorithms and incorporate them in practical systems that can manage the knowledge soup and use it effectively. Such systems should be available within the next few years, and they promise to revolutionize the way knowledge systems are designed and used.

As a closing thought, the following quotation by the poet Robert Frost develops the theme of the opening quotation by Whitehead:

> *I've often said that every poem solves something for me in life. I go so far as to say that every poem is a momentary stay against the confusion of the world.... We rise out of disorder into order. And the poems I make are little bits of order.*

Robert Frost, A Lover's Quarrel with the World

In fact, the word *poem* comes from the Greek *poiein*, which means to make or create. This quotation could be applied to the creations in any field of human endeavor just by replacing every occurrence of *poem* with the name of the characteristic product: *theory* for the scientist, *design* for the engineer, *building* for the architect, or *menu* for the chef. Each person creates new bits of order by reassembling and reorganizing the chunks in the knowledge soup. Frost's metaphor of a lover's quarrel is an apt characterization of the human condition and our mental soup of memories, thoughts, insights, and the inevitable misunderstandings. Any attempt to simulate human intelligence or to support more flexible, more human-like tools must meet the challenge.

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Discussion on the presentation

Query: Concepts are essentially relational and thus in addition to essential attributes concepts have to be defined in terms of related attributes from environment.

Speaker: The word or logic that I use here is conceptual graphs, which deals with concepts, relations among concepts and their context which are defined as a group of statements that describe situations or environments. It is very complicated however it's been discussed in the paper which I have presented under "Laws, Facts, and Contexts: Foundations for Multimodal Reasoning".

Query: …. In Maputo girls and boys of 10-12 years are involved in selling things and doing all kinds of arithmetic even exchanging like Swiss, Portugese, American dollars etc, in short they are aware of money value and its concept but they have poor performance in school in their respective classes. What can we do for these children? Are we enhancing their learning in school, how do we address this issue?

Speaker: I don't have an answer for this. I would say these children learn from Analogy. They learn how to handle money. They have serious trouble learning in the way adults who have already taken all the data and pre-formulated it into abstract concepts and rules do. Their application of abstracts concepts and rules is aside. Even computers are not very good in taking a collection of abstract concepts and rules and in doing a theory-proving from them. I think one problem that happens in our teaching, is that we are trying to teach students to imitate computers, by trying to teach abstract concepts and rules. We try to have theorems proven by them, and that is how we teach today in high schools. I think the idea of going back to analogy may be a better starting point because these children are learning very aptly from their daily lives and are incapable of learning how to imitate computers. It is not the fault of the children but it is we who want them to behave like computers.

Query: A philosophical wit said that a person's epistemology works well in theory but not so in practice and if you define knowledge as "what works" in many ways you can get whatever you want to work provided you make enough adjustments and allowances elsewhere. For example the Soviet economy worked in a way for some people. Would you comment on "Pragmatism" about defining knowledge in terms of what works and does this presuppose this making allowance elsewhere?

Speaker: The definition "knowledge is what works" is not what Pierce said. It was said by many authors like William James. Pierce explicitly was so dismayed by what James and others called "pragmatism" that he renamed his own variant *pragmaticism*, joking that it was "ugly enough to be safe from kidnappers". He emphasized that one needs to test the truth of knowledge. Pierce is known for his work on chemistry, physics and geometry. He was the first American to be invited to an International Conference in Europe to present his work on gravity. He emphasized that science is based on communities of enquirers.

Query: In the context to Analogy- one successful use of analogy in reasoning was done by Darwin when he used artificial selection to assist the concept of natural selection. But does analogy have limits? There is some debate whether this analogy was actually useful in Darwin's theory and whether he could have arrived at the concept using general arguments like variations.

Speaker: If you have a well established theory you must use deduction because the theory is based on so much data it is impossible for a single individual to do as much. You do not make an analogy from a single case. Analogies are made after assessing multiple cases, what is common to them, and what are the exceptions. If there are a sufficiently large number of cases and these are representative cases, it leads to an inductive theory.

Query: You have presented analogy as a primitive way of acquiring knowledge, with induction and deduction at higher orders. What is most useful or suitable for primary school education to develop children's conceptual understanding and enhance their learning experiences?

Speaker: I am not against induction or deduction and I do want to emphasis that analogy is not isolated from logic. Analogy is one of the four methods of reasoning; induction, deduction, abduction and analogy. Analogy is much more general and probably a good starting point to derive general principles. Analogy works at every level- infants to scientists have used analogy successfully. Teaching could be re-organised to bring in analogical reasoning which is very spontaneous and important.

Language and Cognition

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They have a pedagogy attached

Language always comes to us with a certain pedagogic framing attached. So does cognition. When you speak or think, you do so with the awareness that you might get something wrong. As a grown-up, you will catch the mistakes yourself and correct them. But you echo here the transactions in your early life that involved adults who were with you, the child, to do the catching and correcting. Those pedagogues had once shown you the way to speak and to think. Just a second. Had they? Or did you fall victim to a confidence trick that society plays on children?

Do language and cognition in fact arise naturally in every human? Do these phenomena then not come with any pedagogic framing inescapably attached? In that case the framing that a particular society's fussy adults impose on the way a child acquires and keeps her language and her cognition can be removed, if not in practice then at least in theory. That elimination will make the real phenomena in their purity visible to the analyst. If this reasoning holds, I have to catch language and cognition first, and only then talk about how they connect. To catch them, I must unwrap the irrelevant teaching they come packaged in.

But I am terrified. I don't want to tear up and destroy the paper packaging. If I do, the plot of this movie might turn out to make me wish I hadn't. The wrapping might reveal itself as the vital life-saver. Before I touch language and cognition, let me ask the question of pedagogy in other cases. I may find a simple case or two. There I can figure all this out and come back to try my results on the hard case of language. Give me some lateral thinking. I need a walk in the fresh air outside.

Walking, now, that really is a familiar example of a human activity that takes off without special teaching, training, coaching. Society chooses not to frame walking within any system of assistance. But the facts do not force this choice. People can provide special assistance to improve my shuffling walk or more serious problems. Such help can even take the form of a sequence of sessions. The person helping you may frame these sessions in terms of improving your health, as therapy. Or she may frame them as boosting knowledge or skills, as pedagogy. I'll call both of them pedagogy for short.

Now, suppose this enterprise were to network itself and become gigantic. In other words, imagine a future in which the geriatric sector expands. The enterprise of assisted walking takes over the urban landscape. The general population grows really kind and concerned. Every adult taking a normal step automatically classifies it under one of the categories rendered familiar by a system of tutored and assisted walking. In such a world, would today's spontaneous walking remain available for naturalistic biological study? I suppose there would still be backwaters failing to catch up with the geriatric seriousness of such a world. Those backwaters would then harbour some untutored walking of our sort, including my shuffle. Investigators would descend on such pristine spaces and swiftly gather the disappearing data. I could go on, but won't. You get the point. The natural function of walking can get culturalized. If this comes to pass, purely naturalistic investigation techniques will no longer work.

However, in fact we don't yet live under the geriatric regime I was visualizing for the future. We still walk naturally, whatever this may turn out to mean when we attain a more careful understanding of naturalness some day. But we all recognize that dancing is less natural than walking. To be sure, human nature does not stifle our desire to dance the way it does our desire to have a body that can fly all by itself. Learning how to dance is indeed an option the human body has. But a particular body needs to exercise that option actively. By the same token, people distinguish between various dances by giving them names. In our world nobody bothers to identify various styles of walking by name. But dances come with names and classification attached. Even those of us who haven't thought about it recognize this difference between walking and dance.

We can now get back to language and cognition. Consider language first. Do words walk or do they dance? Is language natural the way walking is natural,or cultivated the way dance is cultivated?

This question gives us trouble. Walking and dance strike us as distinct phenomena, not as two ends of one continuum. But language does strike us as being polarized. We place natural speech at one end and cultivated writing at the other end of a spectrum. Our intuitions about where the natural cuts lie seem to view language as an undivided, if polarized, spectrum. The last half-century of linguistic research supports and fortifies our sense that speech really must count as natural. And yet, when forced to assent to an explicit comparison that says speech is like walking and writing is like dance, we hesitate to place speech exactly on a par with walking. Why so?

We hesitate partly because the languages people speak differ systematically on a scale far exceeding the variations in the human gait. Differences between languages correspond to societally differentiated pedagogic models. Children in each society try to measure up to the norms of the speech of their adults, even if direct tutoring plays too small a role to justify the old belief that children are taught how to speak. I solicit your permission to speak of "pedagogy without teaching" wherever norms play an evaluative role in a social structure, a second loosening of the term pedagogy after allowing it to subsume therapy.

So language as a whole ends up looking rather more like dance than you might have initially wished to grant. You move towards this conclusion even if you keep in view the fact that a dancelike pole and a walkinglike pole do polarize the spectrum of language.

We need to finish our work, though. We never made it from language to cognition. Does cognition resemble dance quite as closely as this? As far as people can tell, cognition also comes with a pedagogy attached, which might make us want to compare it with dance. But cognition is as close to an invariant human universal as you can get, inspiring all the rational animal talk. If you take that seriously, cognition obviously parallels walking.

It would be neat to close this section with the claim that language comes out analogous to dance and cognition closely parallels walking. But such neatness lies beyond our reach. The blatantly pedagogy-laden character both of language and of cognition spoils such a picture for us. Language does vary much more dramatically across societies than cognition does.

Stylizing this to the point of denying intersocietal variation in cognition would not be too high a price to pay, as idealizations go, if it would buy us any usable results. But that move fails to find us a way around the fact that pedagogy and naturalness interweave, and need to be watched as they do so, both in language and in cognition. The interweaving in language and the interweaving in cognition seem to work differently, giving us work to do. Trying to collapse the language story and the cognition story is not on.

Not that that kind of conflationary story is unknown to academia; we have tried the conflation in both directions. A grammar-style take on language tried to annex the study of cognition eons ago. This extension enterprise, called logic, is known to go less than half-way and stop. In the other direction, some recent authors try to build an alternative take on cognition and make it tell the whole truth about language. That counter-effort also scores a few hits, but then gets so much wrong that it ends up in disarray as well. If these efforts had been successful, someone like me trying to review the field would not find it necessary to stress the pedagogy attached to language and to cognition.

In stressing pedagogy, I am returning to one of the early classics in the field, Vygotsky (1934/1986).

Socialization as successive coarticulations

I will read Vygotsky (1934/1986) with some deliberate oversimplification. I need to do this because pitting his brain against the other brains we propose to pick will have the effect of complicating his story in new directions, away from the complexities he had stressed which I am playing down.

With these caveats in place, I take Vygotsky to have pointed out, (a) at the empirical level of ontogeny, that language couples the initially independent functions of speech and thought; and (b) methodologically, that it pays to refrain from locking mental functions into strict flow chart relations that stay intact through an individual's life-cycle. In Vygotsky, the mental architecture places functions in different positions relative to each other as the individual grows, and gives the imagination a variable role to play in conceptual development, especially in the early stages. The vital third contribution was to note, (c) at the methodological level, that it helps us less to find out just what a child at a given age can understand as she stands, and that we need to see the child's state of readiness to grow under intimate guidance. This thesis of the zone of proximal development makes Vygotsky most directly pertinent to our worries today.

With this quick outline in place, let us revisit some of Vygotsky's concerns more carefully. In the very early days of the coupling of speech with thought, when the young child has just begun to actively use what sound like meaningful words to us who are looking after her, first of all, her words need massive interpretive mediation to make sense to listeners outside her intimate circle, and secondly she has not yet taken charge of the meaning machine that she happens to be taking little rides on when she speaks and listens. To be sure, her comprehension has always been ahead of her production, to put the matter in the bureaucratic precedence language that so much of the literature seems to get stuck with. But her speech still does little more than barely connect with the meaning that others around her take responsibility for.

That very early stage gives way to the early stage of child language development when the child makes the discovery that not just a few items in her experience, but absolutely every available thing has a name to it. She then starts asking what is this, what is this, on her vocabulary building mission. Collapsing various stages of preconceptual labour in Vygotsky's visualization of infancy, I shall take him to be saying that at this point the child begins to use meaningful words. Words at this stage pick up bits and pieces of situationally appropriate meaning from the contexts in which the child observes them. These early words, or their immediate successors in a more rigorously drawn calendar of the child's progress, carry meanings that a Vygotskyan take regards as preconcepts.

These don't count as formally adultlike concepts until the child knows not only that a rose is a flower and that some flowers are roses, but also that not all flowers are roses. Only when the child makes it to operational and reasoning levels that match adult performance in standard psychology tasks do the bits of her cognition truly graduate to concepthood. Vygotsky's question is, just what does it take for an upbringing to help the child through all her stages into cognitive maturity?

The answer that Vygotsky provides holds the child's mind at a certain irreducible distance from the figure of the adult guide whose pedagogy the child continues to depend on. Even when the human mind has fully matured, in Vygotsky, the mind operates with its own preconcepts, which are too idiosyncractic to ever achieve a complete match with the theoretically adult concepts that form the telos of cognitive socialization. I need to make this point with some care.

Childish preconcepts in Vygotsky's picture do in fact grow into recognizably distinct adult preconcepts in the sense that an adult has access to a complete logical operational system without comprehension gaps. An adult can effortlessly say not only that all roses are flowers and that some flowers are roses but also that not all flowers are roses. At this level there does occur a complete phase transition from child to adult. This part of the distance between the child's preconcept and the idealized adult guide's concept does disappear.

An adult's concept of flower, however, stays tied to her personal experience of flower encounter episodes and to idiosyncratic associations that she knows perfectly well other speakers of the language will not echo. Vygotsky constructs the shadowy figure of the rationality telos as an embodiment of socially generalizable pure formal abstraction. We can read this as a consequence of the condensation rendered inevitable by his working conditions: as he wrote, he knew he did not have long to live. A less formal, more substantive take might have recast the idealized rationality telos as the figure of a superhumanly imaginative and rational guide who simultaneously associates flowers with all the possible resonances that various members of the community find appropriate, distributing imagination types over personality profiles and staging the drama of human diversity in a single all-inclusive mind full of empathy for all possible acquaintances. At this level, nobody can grow into full socialization, since the ideal would be to coincide with society itself. What this picture cannot leave open is the issue of the particularity of a personal history. In Vygotsky, the reference figure is a synchronic entity that summates all possible experiential profiles and therefore cannot itself have even a typical or skeletal history.

This is the irreducible part of the gap between the maturing individual and the telos that guides mental maturation, in Vygotsky. It is this gap that prevents the tools of even adult thought from ever graduating to complete conceptual status.

With these coordinates in place, let us now review what happens to word meaning during the child's socialization as Vygotsky understands it. The typical childish preconcept emerges through an accretionary process whereby piecemeal contextual understandings combine to form a composite image. This tool of early thinking runs into difficulties. Difficulties make the child talk things over with herself. This outer intellectual speaking, in the shift that most readers have come to see as Vygotsky's characteristic contribution, becomes inner speech as the new architecture assembles itself. Inner speech, increasingly accepting the guidance of the helping adult understood more and more as doing this guiding work on behalf of society's rational telos, pushes the child's thinking into formal channels, perfecting her grasp of cognitive operations.

Through this process, the accretion of initial images whereby the child's early preconcepts had been assembled is displaced by serious concept formation strategies. But images are not simply abandoned. The reconfiguration of functions at this stage of development puts a formal system of concepts in charge. This system does not completely supersede the trans-contextual accretion of images. The accretion process continues and is still the inner psychological basis for the preconcepts. Even the adult harbours her preconcepts and retains an affective investment in the personally salient images they refer to. An individual who failed to retain these preconcepts would be unable to grasp any true formal concepts, having no personal resources to anchor them in her affective relations with her world.

Vygotsky keeps stressing the fact that these processes are embedded in the experience of schooling. Formal instruction takes the older child through the important milestones and gives access to the serious formal concepts in terms of which society organizes its adult work. As the child grows into a full encounter with the world of work, her own private narratives give way to a non-fantasy-laden access to that public articulation of what the words really mean.

To put it in terms of narratives, Vygotsky works out for us just how the child gradually goes beyond embedding her words in the little narratives that make personal sense to her and begins to anchor what she recognizes as everybody's words in the grand narratives that society has put in place. In Vygotsky, this story comes through as a transition from speech to writing, from childhood to rationality.

When we reread Vygotsky today, of course it matters to us that his themes retain an obvious enduring value. But it also matters to us that the singleness of rational focus that guides his work both for expository convenience and because of the historical limitations of any vision in his period must now give way to new perspectives on adulthood.

When Vygotsky unpacks the pedagogy, he has schooling in mind, and it leads to a single rational adult society with a scientific grand narrative organizing all the concepts in a unique hierarchy of taxonomies. In Vygotsky's vision, only the inherent openness of science itself leaves any part of this picture non-unique. But other forms of non-uniqueness dominate our attention today.

The taxonomies and other conceptual systems that govern rigorous scientific research, the ones that dominate mass media and other forms of popular communication, the ones that rule the economy, the ones that compete for attention in literary or philosophical elite circles, and the ones that through various political mediations end up in textbooks and other instruments of pedagogy often do not coincide. A violet is a flower? Indeed, if you know it. But violet is a colour term even in climates where no violets grow. An orange is a fruit? This perhaps affects more lives than violets. But even orange counts as little more than a colour term in the many countries where oranges are neither grown nor eaten.

We can get past this multiplicity and reconstruct the core of Vygotsky's insight in terms of notions such as the basic level and prototypes. But the multiplicity, even if these devices rearticulate it a little, will continue to matter in any serious take on education and the conceptual development of children and young adults. In our post-Vygotskyan social reality, adults know that the world into which they are initiating their children has multiple formalizations of relevant rationality. We have various conceptual hierarchies, various sequences presenting what will count as difficult final objects of learning and what as easy initial steps on the way to those objects. This gives children preparing for different sectors of the adult economy different goals to aim for.

We are also aware, partly due to the pioneering work of Vygotsky and his colleagues, that children have diverse cognitive starting points as well because of socio-cultural diversity. Some of us have looked at the cognitive maps of children in tribal societies and have tried fashioning alternative pedagogies for them. Neither the initial childishness nor the final adult state can be taken for granted as a homogeneous system as we navigate.

And now there are post-modern attacks on the grand narratives themselves, undercutting the systematic basis of formal education even as we struggle to make this education accessible to those historically excluded from it. However we may react to these post-modern formulations of the heterogeneity of adult conceptualization, there is no escaping the need to bring narrative into play with theory today. Vygotsky could get away with the view that only in theories do concepts find their final bearings. We cannot, and this is not because of developments in cognitive science, but outside it.

Recursion, music and meaning

Vygotsky did concentrate on the conceptual study of word meanings in child development. But he also saw the importance of marking more clearly, on the basis of experimental work, the boundary between ape and human abilities in this domain. He even saw that one would have to try to teach apes the sign language of human deaf-mutes, and regretted not having the funding to do it himself. Even without the results of such investigations, however, Vygotsky knew that the boundary would turn out to be a robust one.

In other words, if we get hung up on Vygotsky's studies of word level conceptualization, we will miss his own broader point. If we overfocus on word level concepts, we ignore the formal revolution which has propelled cognitive science from the mid-twentieth century onwards into the serious study of the representations and the computational interrelations that form the core of human cognition. Any major text from the generative grammar tradition, such as Chomsky (1980, 1986), can be used to source some of the issues and results that emerged when formal techniques of investigation were used and corresponding new questions were allowed to shape the field.

From the viewpoint of the formalistic linguistics that has made the best use of these new techniques, humans are special in that they alone use recursive representations. Even the brightest apes, despite the cognitively and emotionally most supportive training in sign language, have proved unable to produce sentences like “Sarah says Susan remembers Jill ate two bananas” that involve two or more clauses in an embedding relation. For humans, this is routine.

The representation of a sentence with embedding involves what is formally called recursion. If you draw a tree diagram representing the structure of such a sentence, the recursive relation holds between the lower S or Sentence node that dominates “Jill ate two bananas” and the higher S node that dominates “Susan remembers Jill ate two bananas”. The recursive relation holds again between that S dominating “Susan remembers Jill ate two bananas” which is medium-high in the tree and the even higher S that dominates our full example “Sarah says Susan remembers Jill ate bananas”. We call it a recursive relation because you can keep doing this for ever. A sentence can be lengthened indefinitely by adding levels of embedding. This core fact about human language underlies its nontrivial infinity. But no ape ever embeds S in S. When an ape is taught sign language, the system it learns remains finite.

It takes a while to grasp the import of these facts. Apes and humans seem to share some range of preconcept forming abilities. Even if we deny concept status to the thinking tools that an ape uses, we have decided on independent grounds to recognize even human preconcepts as being of interest to cognitive psychologists. Heuristically, it may pay to set aside for the moment the issue of just where human conceptual development leaves apes far behind, and to focus instead on the undoubtedly human recursive representations that apes completely fail to match.

Chomsky (1980) proposes a distinction between the conceptual system, arguably shared in part by humans with apes and conceivably even other higher animals, and the recursive computation system. His use of the term language or human language to refer to the recursive computation system may bother some of us; let us call it, more neutrally, the formal recursion system. The point is that conceptual system properties, such as the assignment of theta roles like Agent, Patient, Instrument, Goal, Source, Location in a scenario built around a prototypical action, strike the generative linguist as forming a domain that human cognition shares with higher animals. Language taps this domain. Generative grammar does not equate this conceptual system with language itself. Human language anchors itself much more crucially in the formal recursion system, which defines the characteristic properties distinguishing human language from other phenomena.

Generative grammar, especially the branch called generative syntax, has been studying the formal recursion system for two generations now. The study has become more rigorous and technical over five decades. In ways that I cannot clarify here, syntactic research has confined the relevance of conceptual meaning to a narrowly delimitable subdomain of its concerns. I will merely note that words and their meanings are a matter of the details of this or that particular language. Syntax since 1980 has been able to characterize human language as a whole, treating differences between languages as matters of lexical detail that often project into the structure but can be distinguished from the syntax proper, which always turns out to be universal when the lexical details are identified. On the whole, the major issues in syntactic research are formal ones, again in a sense that I will have to sidestep in this review. One interesting result, explored by Mukherji (2000), emerges at the interface where language meets, of all things, music.

Mukherji's argument runs as follows. Linguistics finds it appropriate to characterize syntactic structure formally, on the basis of recursion and related properties. Current research has shown that this characterization picks out a human universal, not different syntactic systems for supposedly different languages. The formal recursive ability of humans that syntax studies does not simply correlate with human musical ability. Once the cross-linguistic differences and lexical-conceptual meaning content is removed from the syntax, a move that linguistics has been forced to make for reasons independent of the study of music, it turns out that music and formal recursion embody, not just similar systems, but absolutely the same formal system in two vocabularies. To put it briefly, language and music are two branches of the same uniquely human endowment, which Mukherji calls the Cartesian mind.

Mukherji's proposal summarized above builds on and updates pioneering earlier work by the musicologist Lerdahl and the generative linguist Jackendoff (Lerdahl and Jackendoff 1983). They based their research on a generative syntax that still invested relatively heavily in conceptual meaning endowed machinery. By Mukherji's time, a massive sidelining of this investment has been argued for on syntactic grounds that are independent of conceptual research and of course quite remote from the music interface.

Current asymmetries in research make it difficult to evaluate or even properly unpack Mukherji's proposals. The linguistic enterprise of cross-systemic comparisons, being more than two centuries old, has piled up a body of solid knowledge. But serious understanding of cross-systemic patterns in music hardly exists, given the infinitesimally small number of musical bilinguals curious about formal issues. But independent factors may push this number up in the near future. We will soon know more than we now do.

While we wait for that research to happen, we can straighten out some unclarities about forms and meanings, or more carefully about representations and interpretations. Some aspects of interpretation, the conceptual aspects, do get packed away when syntacticians make the move of confining lexically governed theta role assignment to delimited lexical modules in the formal system. But other aspects of what we intuitively call meaning remain at large.

Suppose I introduce a couple of new words to make my point, the noun phenoculation and the verb phenoculate. I can phenoculate the words for you at once; I just did. In case you did not notice my phenoculation, I can repeat the operation for you at will. Suppose I just do this from time to time and never bother to define phenoculation for you, never show you a picture of someone phenoculating, and so on. At one level, you will then have no idea what this noun and this verb mean. At another level, though, you will deal with them as if you do. You won't care whether to phenoculate means to exemplify, to concretize, to exhibit, in any detail. What matters to you is that you have seen the word a couple of times, that the text keeps repeating it and sending you back and forth over its earlier and later occurrences in the text, and that this repetition-induced familiarity breeds meaningfulness.

When I say phenoculation the third or the fourth time, my repetition is coreferential to the earlier occurrences. Syntax does not care about reference per se, but it manages the COreference system, which formally interacts with recursion. In other words, the formal system of human language deals with meaning SHARING across different parts of a formal representation quite saliently, and at a level that only humans can handle, no apes, no cats, no elephants. Strictly speaking this is a formal sharing that does not itself constitute meaning or reference. But this sharing, over a stretch of text or conversation, creates much of what we intuitively identify as the impression of meaning. And, crucially, this formal sharing of reference gets managed in pretty much the same way over a stretch of musical performance.

In that sense, music formally elicits interpretation even though we have long known that no constituent of music ever refers to the furniture of the world. To insist that meaningless music and meaningful language cannot share cognitively significant properties thus misses the point. Bits of music establish their meaning sharability through the same mechanisms that bits of language set themselves up with.

Not all scholars in linguistics have pursued this track, though. Some have found it appropriate to persist with the older themes of semiotics, conceptualization, and meanings, and to see if other reasons for being dissatisfied with the classical picture of those phenomena lead to a completely different bunch of alternative models. Human nature being what it is, linguists in that minority tend to ignore the findings in mainstream formal syntax of the generative variety. Obviously we must look at minority figures with some care. I turn therefore to that type of research.

Extended lexical linguistics

Lakoff (1987) serves as a useful point of entry into what may be called a genre of research that he shares with authors as diverse as Kay (1997), Kelkar (1997), Langacker (1986), Pawley and Syder (1983). They exhibit so much methodological diversity that I cannot even speak of family resemblance. But they share a thread of common concern. The very success of generative syntax leads to a certain neglect of lexical specificity and the concrete choices typically made by native speakers. These authors try to characterize aspects of languages familiar to native speakers that defy the new formal methods.

I loosely describe their work in terms of Extended Lexical Linguistics, the heading of this section, since they seem to agree that the coherence of a word in a language, such as the English verb "buy", is a matter of substantive seriousness that formal approaches often incorrectly ignore. In other words, they begin from the default assumption that a word like "buy", even if it has several meanings, finds a way to connect them. Starting from a point like this, the impulse of Extended Lexical Linguistics is to explore extensions across the boundaries of this particular word.

Lakoff's writings are popular enough in our day and age that I can assume familiarity with the basics of Idealized Cognitive Models. You surely know, or can guess, how the sense of "buy" in "I will buy some potatoes" stretches to let you say "You are saying Venkatraman let you down, but I don't buy that". This is the part of Extended Lexical Linguistics that explores the ways in which the various meanings of a given lexical item are connected to each other.

But notice that those speakers who routinely prefer to use the verb “purchase”, such as many Indian speakers of English, can handle this semantic diversity of “buy”, but do not mimic it in their use of “purchase”. An Indian who says “I will purchase some potatoes” does not say” You are saying Venkatraman let you down, but I don’t purchase that”. On the face of it, this is a limited, one-shot fact, and there is nothing interesting to say.

But now watch. Some of you may have looked at generative syntax and may vaguely remember seeing examples of Raising to Subject, a syntactic transformation that handles the relatedness between a diffuse sentence like “It is likely that Ali will come” and a compact version such as “Ali is likely to come”. Think about the people you know who avoid using “likely”, even though they understand it, and who prefer the heavier adjective “probable”. I suspect you will find that very few, if any, of these people would ever say “Ali is probable to come”.

Or consider a trigger for the syntactic transformation known as Dative Shift, which handles the alternation between “Manisha gave five thousand rupees to the church” and “Manisha gave the church five thousand rupees”. This works fine for simple verbs like “give”. Now get back to our friends who use bigger words where a smaller word would do. Would even those friends take a sentence like “Manisha donated five thousand rupees to the church” and turn it into “Manisha donated the church five thousand rupees”? I think you will find that even they would recoil from this. Dative Shift doesn’t apply to “donate”, though it does to “give”. Raising to Subject doesn’t apply to “probable”, though it applies to “likely”. Extension from the core meaning of commercial transaction to an epistemic meaning doesn't apply to "purchase", though it works for "buy".

The Extended Lexical Linguistics approach to this particular problem has not been worked out, though some of these observations are familiar in the literature. I'll have a shot at it myself, just to give you the flavour of the basic move made in that genre of research. A linguist of that type might say, listen, the short words represent basic level percepts, and the bigger words have a semiotics that ties them down to technical term work. So they are not up for grabs and cannot be extended in the ways that the lightweight words can be. Extension works with the basic level and will only hit the words that belong there, not with words like "purchase, probable" that are one remove away from that level.

I'll walk you through another case that might be of greater general interest. Get back to that "buy" sentence for a moment. Now note that one doesn't extend the verb "sell" in the same fashion. One is not free to say "I was saying Venkatraman let me down, but I couldn't sell you that". Of course some stretching of "sell" is not unheard of; it is indeed possible to say "You won't be able to sell such a story to your girl-friend". But my point, which I suppose you accept, is that "sell" stretches less far than "buy" does. Why should this be so?

Wearing my Extended Lexical Linguist hat, in my capacity as a direct student of Ashok Kelkar's, I can propose the following account. The lexical asymmetry between "buy" and "sell" makes "buy" more basic. This stands to reason, since in real life transactions buyers are more numerous and thus more typical than sellers, just as there are more readers than writers. Likewise, we can and do stretch the verb "read" when we say "I don't know how to read this man's actions, he is so mysterious", and we find it impossible to stretch the verb "write" in a comparable way, we never say "I write my actions so convolutedly that nobody can read them".

Pedagogy, multiple symbolization, and translation

I have not, so far, insisted on the question of language AND cognition. Normal human self-questioning about what one knows has never departed, or never departed very far, from the model of how a teacher and a pupil traditionally talk to each other about the work of teaching and learning, perhaps with the pupil internalizing the teacher's role. In this sense, cognition by humans always appears in pedagogically cultivated forms. Normal questioning about such cognition thus always frames itself within the terms of some pedagogy. Asking questions about human cognition without reference to pedagogic frames is not an option available to us.

The way the question of cognition nowadays appears to the average scholar is shaped by the fact that, disregarding this default pedagogic framing, philosophers who take the primary responsibility for organizing our understanding of meaning and cognition have often tried to fashion such an option, acting on a logicalist impulse. This impulse of theirs seeks to disengage our discourse about cognition from the concrete sequentiality of pedagogy, and from the corresponding need to provide tentatively viable concepts even though these ultimately have to be outgrown. The logicalist approach supposes that any subject, institutionally available as an academic discipline (a set of serious discourses), can be reduced to variously organized arrays of formally simple primes. It supposes also that these primes, through a rigorous axiomatic unpacking of their interrelations, can parsimoniously derive all the complex concepts and propositions that the discipline uses.

These suppositions operate at the level of the full critical discourse of adult members of university communities, and have various effects on educators who deal with younger students and who often, inappropriately, try to fashion their work on the basis of too close a reading of what the universities produce for reasons of their own.

Now, scholars who believe in the usefulness of logicalism's restatement of a discipline's results see the activity of such redescribing as a matter of arranging the results in formal packages whose coherence and consistency represent what the best minds in the discipline can be said to know. The enterprise of formalizing such systems naturally elicits second order projects of metasystem building. The vision of a fully understood language of a unified science that will have brought all disciplines under maximally parsimonious reduction, and of a fully understood scientific language wherein coherence, consistency and economy can be visibly maximized, continues to serve as a telos guiding scientific formalization. In this sense the logicalist programme is alive and well, and is one of the major presences in the study of the language-cognition interface.

If we accept such a picture of the realities of what there is to know, a psychology that considers problems of learning should take as its point of departure roughly this portrayal of the ultimate content of serious adult human cognition, and should ask how a child gets there. This relation between a logicalist account of the goal and a psychological account of the path places the burden of pedagogy entirely on the psychology. But such assumptions conceal from the view the important fact that the standard portrayal of the serious adult goal is tacitly framed in a pedagogic conceptualization. It has been necessary, in the remarks above, to refer to academic disciplines, and to the best minds in the field. These are allusions, if not to teaching, at least to watching people learn and evaluating their performances, which belong to the broader pedagogic enterprise.

But there are at least two reasons for not claiming that the material we have reviewed forces us to press for a simple pedagogic turn in the study of language and cognition. First, domains of language use are organized in one fashion in the world of work, another way in the world of media and public communication, and yet another way in pedagogy proper. These are three distinguishable phenomenal realms. To approach the study of how they co-articulate, we need to first have these distinct takes on cognition, and we have not yet been able to catch them. This is a problem for research in our period, which we need to do, not to review.

The second, related point is that the easy and the difficult in pedagogy fail to match the simple primes and complex assemblies of the formalization in the stories sciences tell about themselves. Therefore we will achieve only limited success if we try to carry over the style of scientific concept packaging into our understanding of how the easy and the difficult play out in pedagogy. Issues of more opaque versus more transparent expositions in public communication present yet another domain into which one cannot usefully export the formalization style if advances in our understanding are the goal.

The differences just pointed out have long been obvious in practice to natural scientists, who tend to respond to this state of affairs by treating both the teaching of science and the technological application of scientific knowledge as atheoretical enterprises not integrable into its rigour. In contrast, science itself appears in their work as a body of bodies of theory.

This appearance continues to shape our default conceptions of both language and cognition.

However, current, not exclusively logic-driven work on the role of language and translation in the practice and teaching of science (Sarukkai 2002) speaks to classical work (Vygotsky 1934/1986) on the way image-based preconcepts must, as the adolescent schoolchild grows into serious knowledge, turn into the abstractions operative in society's adult, industrial economy. Taking these matters on board means supplementing the logical derivation approach with pedagogic build-up perspectives on how various real learners converge on sharable knowledge. The task of such supplementing is cognate to inquiry focused on how a person acquiring language also learns what one might call precognitive material that does not itself constitute knowledge but categorizes or frames the knowledge that the person acquires (Sperber 1975).

The present survey of where the field stands is now ready to encounter Sarukkai's (2002) argument that formal abstract concepts are embedded in multiple semiotic systems and need to be placed in translation mediations that never settle down. On these assumptions, the formalism that officially explicates what scientific language codes are like is relativized to intercodal mediations that Sarukkai places in a pedagogic framework. The methods of translation studies enable us to coarticulate our distinguishable questions about simple/ complex, easy/ difficult, transparent/ opaque. Given a translation studies approach, the domains of adult scientific practice, of science pedagogy, and of the media can be kept apart and yet brought into meaningful conceptual connection.

Working in the context of anthropological research, Sperber (1975), not unlike Sarukkai (2002), had stressed the role of multiplicity in the linguistic and cultural code, which Sperber was willing to call semiotic if one was going to be careful not to confuse the semiotic with the semantic. In his account of what he broadly calls symbolism, Sperber notes that statements and symbols disengaged from normal "rational" functioning refuse a direct propositional interpretation and thus step into alternative, non-semantic sectors of semiosis. Sperber endorses but reconfigures structuralist work on the semiotic role played by myths and other culture-forming symbolic elements. For him, they are not themselves semantically interpretable; rather, they work to structure the cognitive coordinates of memory and attention in such a way that normal conceptual classification and semantics are supported by adequate affective preconceptual systems. Here Sperber continues the work of Vygotsky as construed in this survey.

In an obvious way, Sarukkai's emphasis on the role of metaphor in scientific research and writing practices connects with Sperber's work on the cognitive anthropology of the symbolism circumscribing what humans know, and ultimately with Vygotsky's work on how serious knowledge relates, and relates in the structure of language itself, to the not yet properly understood affective and imaginative coordinates that make human knowledge human.

But the recognition of metaphor in scientific thinking is a familiar point that goes back a long way. Sarukkai's distinctive contribution lies elsewhere. He draws on postmodern translation theory to underline the proliferation of meaning generating systems unpacked by the diversity of writings in a science article, the natural language prose, the artificial language formalism, the schematic diagrams, the photographs of the output of the experimental apparatus, and other symbolizations. Sarukkai notes that the scientific imperative of enabling the mutual substitution of equivalents under specific assumptions forces the text, after it has allowed meanings to proliferate, to then rein in this proliferation. The result is that particular bits of the formalism, of the prose, of the diagrams get equated with each other. These equating actions are partly unstable and subject to revision under conditions defined by the scientific practice itself. Thus the textual work of a science article opens up the fields of meaning, recloses them by equating certain particulars, reopens the fields by making some identifications available for revision, and so on.

Sarukkai crucially refers to the pedagogy surrounding science writing when he notes that a science book proceeds on the assumption, made explicit in the discursive practices, that the reader will have to work hard to keep pace with its development of the topics. In Sarukkai, the deployment of the apparatus of postmodern translation theory to explicate the mediations between the symbolizations amounts to an initial account of the topologies of access. Only through a more careful understanding of these translatability relations can we hope to move towards a better articulated account of possible or actual pedagogies that circumscribe and shape the work of scientific research and exposition.

One way of looking at the material we have surveyed takes a leaf out of Sarukkai's book with a side glance at Vygotsky. The initial take from Vygotsky gave way to a proliferation in the middle decades. We lost sight of the simple adult-child dyad and of the zone of proximal development. Now the field is perhaps ready to reidentify bits of different symbolizations and rein in the excessive proliferation of meanings. We are ready to ask how the mathematics that plays big brother in the symbolic systems can spell out more explicitly its translation equations with non-mathematical components of science writing, in the context of a theory of images and their mappings with non-image expository devices. As we thus expand our understanding of the languages of serious scientific and mathematical discourse at the top of the adult cognitive tree, we equip ourselves to handle the way this has to reach other parts of the tree, including various children and the increasingly various adults. We also learn how to ask more carefully our questions about how the visible languages on the bark of the tree are related to the cognitive sap and whatever else is inside. But perhaps putting the matter in these terms amounts to barking up the wrong tree.

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Discussion on the presentation

Query: The context of multiplicity of expressions in science processes is well known and understandable. Has there been a study connecting multiplicity and cognition, such as, do people or students who use multiple expressions improve their cognitive capabilities? Indian educationists are of the view that the pictorial mode, drawing pictures, is usually not employed or less employed in science in India as compared to western countries. The Indian education system uses less number of pictures to represent an equation, physical process or theory, in contrast to extensive use of pictures in western countries.

Speaker: If one tries to solve a problem then this is cognitive progress and when cognitive progress happens the going is rough. Multiplicity of expression is rough to cope up with, and when a child learns this task, it leads to cognitive development. Multiplicities of codes is a hurdle to cope up with when a child learns in two languages or learning of music or something, and there is a mediation between two systems this task elicits cognitive progress. I don't know if there is a study directly addressing multiplicity of expression as a helping factor, although there has been early work in this field.

Query: Regarding the issue of building up languages of discourse in science textbooks, there is a strong possibility of socio-political factors influencing this discourse. For example take the concept of "fields" as in electric or magnetic fields. In Hindi or any regional language the terminology used (due to socio-political factors) in teaching science and technology manipulates "scientific terms" making it difficult to follow. An example is the terminological use of the word "field". In Hindi texts "kshetra" is used for field, while in Gujarati it is "khet". There is confusion in the use of "khet" as it implies farm-field, which can confuse students.

Speaker: On socio-political factors on the choice of "Kshetra" in Hindi and "Khet" in Gujarati, I have written an article earlier titled, Sanskrit, English and Dalits, in the "Economic and Political Weekly" (April 15-21, 2000, Vol. XXXV No.16, pp 1407-1411), which can be referred.

Query: This is regarding the link you made between N. Mukherjee's concept of strong identity between "Music and Language". There is no culture where rhythm is not linked to early forms of humanization. It helps to memorize, to represent and make relations with external objects, and later on to structure beliefs. This identity, which Mr. Mukherjee talks of, is it Epistemological, Ontological or Methodological?

Speaker: Mukherjee argues that there is a single entity, which he calls a Cartesian mind. He rejects modularity for the mental processes he says there is one mental process, i.e. cognition.

Query: Your presentation talks more about language than cognition. Is there a relation between thought and language in terms of cognition? Going back to the example you referred to, of a 2 yr old child who discovered the fact that everything has a name, and that point describes merging of two independent sources: one is cognition-thought that children developed separately; they also develop language separately. They learn that there are two sources which match and interact. Therefore the issues raised need to be supplanted by cognitive aspects, which need to be researched from this background: what is the relation between thought (cognition) and language.

Speaker: I have left out cognition in the presentation but it is there in my paper.

Query: There is a very important connection between language and music, melody and speech. It is known that children at their babbling stage learn the melody pattern of their speech. Therefore, in every culture they use melody to memorise poems. And everyone is well aware that we can memorize a poem much better if it has a melody associated to it, at the same time we can remember a melody much better if it has a poem associated with it.

Speaker: About prosody our current perspectives are underdeveloped. Linguistics is still lagging behind. Our current view of cross structure in syntax is insufficiently sensitive towards prosody. Research findings have shown that prosodic elements like structures are also syntactically relevant.

Query: Are there any studies in linguistics on adjusting speech or changing what one said, so meaning is highlighted, or to make clear use of rephrasing what someone else has said?

Speaker: There are a lot of self-correction studies in conversation analysis. A study in the Journal "Language" published in the 80's, reported that there is a tendency for the interlocutor to steer you towards correcting yourself because if someone else corrects you, you are losing face.

Query: Can I make sense of what you are saying with reference to mathematics by substituting mathematics for music and understanding children's difficulty in learning mathematics? Fundamentally language and how language is a part of mathematics is important. There is mathematical language of which symbolism is a part and natural language which we have to use in order to talk about mathematics. These can get us into deep layers of confusion, to which we can relate some of the problems that students have in learning mathematics. Whether or not music has universal grammar we may claim that mathematics does have universal grammar and perhaps the belief in universal grammar is what causes a problem in the learning of mathematics.

Speaker: According to Sunder Sarrukai, mathematics is a game in which you keep changing the rules, and in between the games with rules in them you do things, such as, you take symbols and try them out in various directions, interpreting models. Mathematics does not have a universal grammar but the universal possibility of turning something into a grammar, and if that is the case children need to be encouraged to play with rule bound things. Mathematics can be made interesting for children by playing with languages to understand mathematics, which in turn would encourage learning.

Query: Regarding cognition and brain development a lot of research exists on “neuro- cognition”. How can language be learned after the age of 7-8 yrs? If you want to learn dance or sports one finds difficult to learn after 7-8 yrs but is it same with language? Is it possible to learn language even after a given age?

Speaker: There are two aspects, one, if a person has for some pathological problems had no access to language, which is crucially needed for language to take off, and two, if a person has learned only one language till the ages of say 15 and then he/she gets access to the second language. The first can be seen through unfortunate cases, but it is difficult to separate language exposure deficit from the general pathology and there is not enough data to answer the question, but language exposure is crucially needed at an early age and hence the concept of critical ages.

Unit 2

Science, Technology and Mathematics Education

International Trends in Science Education Research

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Abstract

This presentation will examine some of the unprecedented developments in science education research in the past three decades (1974-2004). In the last 30 years, there has been a huge increase in international professional research activities (as is illustrated by this conference), resulting in an increased output of publications in science education research from a wider range of nations (as is illustrated by the number of new journals, especially in the English language), and an increased amount of professional development initiatives (as is illustrated by increasing interactions of professional societies, employers and universities and the growing importance of the roles of science teachers' associations in many countries).

At the classroom level throughout the past 30 years, there has been a constant call for more relevant science education (as is illustrated by a growing interest in post-compulsory schooling and how to provide appropriate curricula and assessment in science education) and for greater inclusivity in science education (as is illustrated by the need for science curricula that do not simply reflect social and cultural stereotypes of science).

During this period, there has developed a great diversity of the types of research being conducted in science education. At one end of this spectrum

are large-scale assessment programs (as is illustrated by the Trends in Mathematics and Science Studies (TIMSS) and the Program for International Student Assessment (PISA) studies which provide both national data and international comparisons). At the other end of this spectrum are small-scale studies of the work of science teachers in individual classrooms (as is illustrated by action research studies and the detailed documentation of expert practices). To be able to conduct studies of this range, over the past three decades, there has been an increasing acceptance of alternative genres of science education research and an acknowledgment of their own strengths and weaknesses.

This presentation will expand upon the issues described above with examples from different countries. However, from my perspective, despite all the developments in science education curricula, assessment and research, there is still need for a greater understanding of the relationships between policy and practice and a realistic expectation of what science education research can contribute to practice. This certainly should be a major part of the work of science educators in the next three decades.

Introduction

In this review of developments in science education research over the past three decades (1974-2004), I will refer to four aspects that I believe are worthy of reporting. An alternative approach was to analyse the literature for specific research investigations but I considered that too daunting a task and would be inclined to be reflective of my own interests and be related to my own research.

The four aspects that I believe have defined science education research over the past 30 years are (1) the huge increase in international professional research activities, (2) a constant call for more relevant science education, (3) an increase in the diversity of the types of research being conducted in science education, and (4) a need for a greater understanding of the relationships between policy and practice and a realistic expectation of what science education research can contribute to practice.

Increased international professional research activities

I shall consider firstly the increase in English-language publications in science education and secondly the increase in the range of scholars involved in educational research.

Increase in English-language publications

In the past 30 years there has been a large increase in international professional activity in science education research (as is illustrated by this conference), resulting in an increased output of publications in science education research from a wider range of nations (as is illustrated by the number of new journals, especially in the English language), and an increased amount of professional development initiatives (as is illustrated by increasing interactions of professional societies, employers and universities and the growing importance of the roles of science teachers' associations in many countries). But it has not always been like this. The United States was among the first nations to treat science education and research in science education in particular as a serious field of scholarship long before other nations; the National Association for Research in Science Teaching (NARST) was established in 1928.

Indeed, 30 years ago, many of today's well-known science education research organizations had only just started or did not exist. For example, the Australasian Science Education Research Association (then as the Australian Science Education Research Association) held its first annual conference in 1971, the Gesellschaft fuer Didaktik der Chemie und Physik - GDCP (Association for Chemistry and Physics Education) was founded in 1973, the Mathematics Education Research Group of Australasia Inc. (MERGA) held it first meeting in 1977, and the International Organisation for Science and Technology Education (IOSTE) was founded in 1979. More recently, the European Science Education Research Association (ESERA) came into existence in the mid 1990s and held its first meeting in 1997.In addition there are a few other international organisations in science education and many national science education research organizations that have come into existence during the past 20 or 30 years.

What is most notable is the increasing range of output of publications in the English language in science education from a wider range of nations. Previously, I looked at the authorship of articles in the *JRST* (Treagust 2000). In the ten years from 1980-1989, 80% of *JRST* authors were USA-based and the remaining 20% were from other nations - representing a wide range of countries - with English-speaking Australian, Canadian, Israeli and Nigerian authors being most consistently present. However, there were many authors from countries where English is not the first language – Brazil, Jordan, the Netherlands, Thailand, Venezuela, Greece, Switzerland to name a few.

Of the authors who published in *JRST* from 1990-1999, 72% were USA-based and 28% were from outside the USA, with a small increase in the actual number of different nationalities represented, with publications from

Portugal, Germany and Spain being more in evidence. *JRST* has been considered for a long time to be the premiere journal in which to publish science education research and until quite recently was one of the few places where foreign scholars could gain international recognition for their research and be published outside their own countries. So *JRST* was a publication goal for international scholars - and this was always advantageous in being considered for tenure and promotion!

In some ways, that there has been an increase in international authors in *JRST* is a reflection of the esteem that *JRST* is held in by the worldwide science education community. I make this statement because in the past 30 years, there have been several other journals that now have a much stronger international presence than previously and hence there are many more outlets for all scholars to publish their work.

However, one must not think of the internationalisation of research in science education (and mathematics education) as being only centred on English language countries. From my colleagues in Germany, I know of students from many nations studying at German universities who have the possibility of writing theses in either German or English. In addition, the European Science Education Research Association holds a summer school every two years for doctoral students in science education and the language of discourse is English. This says a great deal about the willingness of European doctoral students and academic colleagues to work in a language other than their first language.

Indeed, the willingness to speak, write and present papers in English is a hallmark of the internationalisation of science education research. There is an increasing willingness for nationals of non-English countries to write and present in English and, looking at the published literature, there is an increasing output in English from nations previously largely inactive on an international scene - examples, Argentina, Brazil, France, Greece, Korea, Portugal, South Africa, Spain, Taiwan and Turkey.

Increase in the range of scholars involved in educational research

In the past 30 years, there has been considerable increasing interest in the findings from science education research by physicists, chemists and biologists as well as an increasing interest in science education research at prestigious science conferences such as the American Association for the Advancement of Science. Other examples are the Gordon Research Conferences which primarily deal with the cutting edge of science; at these meetings, there are no written papers or proceedings, speakers are invited, and conference attendees present poster sessions in the evenings. In 1999, I was a guest speaker at a Gordon Research Conference on Innovations in College Chemistry Teaching that brought together people with special interests in chemistry education research; as indicated by the title, the majority of those attending were chemistry academics and professors with interests and responsibilities in learning about ways to improve undergraduate chemistry education. Similarly, in Australia, I have attended conferences hosted by the Chemical Education Division of the Royal Australian Chemical Institute, mostly attended by chemists who are interested in how to improve student learning and to examine ways of improving teaching; they are keen to learn about science education research that can inform their educational practice in chemistry.

Indeed, at the tertiary/university level in science and engineering, I believe that there is a slowly growing awareness of what colleagues in science education have to offer and there is a growing willingness of colleagues in the sciences to be innovative (see for example a teaching and assessment program in engineering reported by Mills and Treagust, 2003). Furthermore, in some countries, there is an increasing willingness to consider alternative forms of assessment in schooling at all levels.

At a secondary school level, one of the most productive approaches to science education has been based on a coalition of professional societies, employers and universities. Professional development is a way of introducing teachers to research findings but there is lack of extensive research on the effectiveness of both voluntary and required professional development. Similarly, in many countries there are increasing roles of science teachers' associations in promulgating research ideas. Furthermore, the recognition of the importance of good materials - curricula, teachers' guides, educational documents – based on the findings of educational research is in the ascendency.

Calls for more relevant science education curricula and assessment

Throughout the past 30 years, there has been great interest in providing a relevant science education for school-aged youth as is illustrated by a growing interest in appropriate curricula offerings in science for post-compulsory schooling and different forms of assessment in science. The major concern has been the achievement of scientific literacy.

In their review of the status and quality of teaching and learning of science in Australian schools, Goodrum, Hackling and Rennie (2001) refer to Fensham's (1997) overview of the changing nature and goals of science education during the past 50 years to explain why it has failed to promote scientific literacy. For various vested interests, changes in curricula are not always welcome. For example, in the state of Victoria in Australia, the course entitled Physical Science, designed to include aspects of the interfaces between science and technology and science and society, was deemed not acceptable for entry to certain faculties in one university, notably in medicine and science, resulting in the demise of this subject innovation in science (Fensham, 1987). So despite the success of the curriculum in being designed to meet the needs of a broader section of the school population, the conservative requirements for university entrance did not enable this approach for increased scientific literacy to be achieved.

Recently, Fensham (2002) has stated his disappointment that the goal of different science education for various academic groups in schools has not been achieved in the majority of nations. In illustrating what has not eventuated in the 'Science for all' movement, Fensham examined changes in science education from a wide range of international perspectives, including American, Asian, British and European endeavours, explaining that the failure of 'Science for all' has arisen primarily because the curriculum has remained within the existing school setting, organisation and policies. Fensham recommended that this impasse can be addressed by using information gathered from societal experts and from the media in order to develop socially-derived content for inclusion in new, more relevant, science curricula that are important to citizens' personal lives. Perhaps all science educators need to become more involved in the socio-political aspects of curriculum. Not only are teachers and university scientists' conservative and accepting of the existing curriculum, but also so are science educators (Treagust, 2002).

The recognition of culture

Outside influences on the science curriculum can come from persons within the culture as described above by Fensham. However, the notion of culture and what this term means in the context of classroom teaching and learning and how a better understanding of this phenomenon can move science education research forward is an area needing further research. Indeed, the initial research on cultures was not conducted by science educators; rather science educators have become aware of this research and are using it to interpret life in schools and classrooms and thereby gain a better understanding of activities engaged in by teachers and students (Cobern, 1998). In this realm of activity, I believe that there is a need to compare research findings in the Anglo/American community with research findings in other languages and to investigate any differences and to note that these differences are often subtle.

Concerns for post-compulsory schooling and inclusivity

In most nations, there are increasing numbers of students staying on beyond compulsory leaving age (typically 15-16 years old) and over the past two decades at least there have been consistent calls for a curriculum to meet their particular needs. Consequently, there is a growing interest in post-compulsory schooling and what this means for an appropriate curriculum in science education. Linked with this concern is an interest in scientific literacy and assessment at all levels of formal schooling and beyond.

An issue of concern in science education over in the past 30 years has been the lower retention rates and achievement of girls in science, particularly the physical sciences. Among the issues for investigation were that the pedagogical practices reflected social and cultural stereotypes that were masculine. In response, curricula have been designed that are gender-inclusive; several books have attended to this issue and a biennial conference - Girls And Science And Technology (GASAT) – has supported researchers with these interests and publishes conference proceedings. Recent studies show that these differences in favour of boys are either much less, having achieved parity or that girls now out perform boys.

Many nations now have large numbers of children of immigrant parents in their schools and more attention needs to be given, and in some cases is being given, to their education in science which most often is in, to them, a foreign language. In a similar vein with students in multilingual classroom as in South Africa or for Spanish speakers in mainstream US classrooms, there is a growing body of research about how teaching and learning can be made more effective but much more needs to be done.

The last issue is the need for more research for those students with disabilities of different kinds and whether or not these students should be in the mainstream with all students or be taught separately. In western nations my perception is that this is of growing concern and is a somewhat controversial issue among teachers, parents and administrators.

Diversity in research in science education

Science education research is not conducted within one paradigm because there are too many fundamental differences about the nature of science education. Indeed, science education is not quite a research paradigm there is too much disagreement at a fundamental level. Nevertheless, science education research is characterised by the issues it addresses and these include Learning, Teaching, Educational Technology, Curriculum, Learning Environments, Teacher Education, Assessment and Evaluation, Equity, History and Philosophy of Science.

Research methods in science education draw on perspectives from philosophy, psychology, sociology, as well as history, anthropology and economics. During the past 30 years, there has developed a great diversity of the types of research being conducted in science education and there is a growing acceptance of these different research genres, often borrowed from other disciplines.

At one end of this spectrum are large-scale assessment programs as is illustrated by the Trends in Mathematics and Science Studies (TIMSS) and the Program for International Student Assessment (PISA) studies which provide both national data and international comparisons. The genesis of these major international comparative studies is concern about scientific literacy and a search for more in-depth (comparative) information. These studies have resulted in a huge number of publications, specifically international and national reports, theses and dissertations and edited books. However, few of these publications are published in science education research journals or conferences and somehow these studies do not have the necessary impact on the science education community (Olson, 2004).

At the other end of this spectrum are small-scale studies of the work of science teachers in individual classrooms as is illustrated by action research studies and the detailed documentation of expert practices. To be able to conduct studies of this range, over the past three decades, there has been an increasing acceptance of alternative genres of science education research and an acknowledgment of their own strengths and weaknesses. Recent approaches that were used less frequently in former years are case studies, narrative accounts and first person accounts.

Research on the status of science teaching

In non-western countries, science teachers have high status but the remuneration is very poor. In western nations, status of science teaching is declining and science teaching is no longer a career of first choice. This scenario is a problem because of the ageing workforce of science teachers and there would appear to be a lack of well-qualified people wishing to enter the science teaching profession. There is concerted action in some countries to address this problem by encouraging scientists to teach after a very short period of induction into the profession. Research shows that the results so far are mixed at best. As a consequence, there are problems with replacing current teachers and concerns about the viability of subjects like physics in many schools. Similar problems exist at the tertiary level with many universities no longer having separate departments of physics and chemistry.

In addition there are problems with the science teacher career structure (which includes other teachers) and there is frequently friction between professional development, salary/career advancement and employers in some countries.

Research on the impact of technology on teaching

Research on the impact of technology on teaching is of key importance as is illustrated by the review by Linn (2003) which looked at this impact in terms of science texts and lectures, science discussions and collaboration, data collection and representation, science visualisation and science simulation and modelling. As the review showed, there is an increasing use of computers in schools but more research is still needed to investigate how students learn science with computers? Similarly, there is an increasing use of on-line resources but how beneficial are these to learning science and is it better to learn science in a synchronous and asynchronous manner with on-line resources? Related to this issue are the problems faced by teachers when using computers in their teaching. Some schools require students to have lap-top computers and research is needed to demonstrate whether or not this is the way to improve/enhance learning.

Concerns about scientific literacy

Science education reforms in a number of countries (for example, Australia, New Zealand, England, and the USA) promote a standards-based definition of scientific literacy for all people such that they can understand science and apply the big ideas to realistic problems and issues involving science, technology, society and environment (Hand, Prain and Yore, 2001). At the same time researchers are examining the specific roles of reading and writing in science education (Yore, Bisanz and Hand, 2003).

The Programme for International Student Assessment (PISA) conducted by the Organisation for Economic Co-operation and Development (OECD) has a different approach to the Trends in International Mathematics and

Science Study (TIMSS). PISA is aimed at reading, scientific and mathematical literacy and the testing is in terms of mastery of skills deemed essential for daily life. The results from TIMSS and PISA studies have provided a very strong incentive for each nation's government to look at the status of science education. Indeed, many of the countries that performed less than anticipated on these assessment measures have obtained government funding to help address the perceived weaknesses in science education. However, as indicated in a recent *Scientific American* article, it is not at all obvious that revision of science curricula in an attempt to increase scores as measured by TIMSS is an optimum way to direct our energies in science education. In almost every nation, there is a desire to ensure high levels of scientific literacy among school-aged youth and TIMSS data do not necessarily provide this evidence.

From my perspective, science education research would seem to be at some kind of crossroads and we have the opportunity to bring different thinking to this situation based on information gained from colleagues in different nations. We have increased interest and opportunities to engage in discourse and share our work with a wider range of colleagues at different conferences in different countries, but how do we utilize this information in a productive manner for our own nation? We also are faced with the challenge of how to translate research findings in science education at national and international meetings to what happens in the school classroom and the university. How do we do that effectively?

Research interests in science education

Most research in science education is on the practice of teaching and learning, together with assessment, evaluation and teacher education; there is less on philosophical issues. A look at the research literature in science education would indicate that in the past three decades, the work was dominated by research concerned with the flowing topics. I have identified major references or recent reviews for each of these topics and apologise in advance to colleagues who may feel that I have overlooked their work

- Children's understanding and learning of scientific phenomena (Miller, Leach and Osborne, 2000; Wandersee, Mintzes and Novak, 1994)
- Conceptual change research (Duit and Treagust, 2003; Hewson, 1996)
- Constructivist views of learning/teaching (Fensham, Gunstone and White, 1994)
- Nature of science (McComas, 1998)
- Perception studies - classroom environment, attitude (Fraser, 1994)
- Equity and gender issues in science (Baker, 1998; Rennie, Parker and Fraser, 1996)
- Scientific literacy (Yore, Bisanz and Hand, 2003)
- Assessment/Evaluation (Tamir, 1998)
- Science Teacher Education (Abell, 2000; Anderson and Mitchener, 1994)
- History and philosophy of science (Duschl, 1994)

I am sure there are other areas of importance that I have overlooked in this brief review.

Science education influencing policy and practice

As a domain, science education research grows by its own activities and also by being open to outside influences. However, looking at the world from an insider's view of science education research, occasionally we must ask ourselves what lasting and significant influences are we having in related academic domains? Sometimes I believe that it is difficult to see what this influence might be! Certainly we produce a lot of good research in a range of high quality journals that are recognized by the science education international community. But how much does this body of research really influence persons in academic domains other than our own?

One way that our research in science education can have more influence is by writing not only for ourselves, but also for groups in other domains. No doubt, a desired outcome is to influence the political process in education by our research, but my experience tells me that this is rarely the case or at least not in the short term. Indeed, to the best of my knowledge, most researchers in science education do not write for journals outside science education involved with educational policy, so this lack of influence is not surprising as the policy people generally do not read our journals.

Fortunately, we do regularly write for science teachers and for science teacher educators – and frequently we are members of these organizations. However, this kind of writing receives less support than it should do from within the research culture of universities. As a profession designed to do research that can help secondary and elementary teachers and students and science teacher educators with their work in science education, it would be remiss of us not to share this knowledge with the people who can best put it into practice in school classrooms. Another group we hope to influence and with whom we share experiences is the university and college science sectors.

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Discussion on the presentation

Query: Regarding professional development of teachers are universities creating any programs to give Bachelors (graduate) degree in science education? This would be to train science and technology teachers to teach at primary level?

Speaker: Most universities have programs for teacher education and streams for a B.Sc Education in departments of science and mathematics education. There are teachers training institutes in Australia where training is given so that they teach in relation to science education and technology but I cannot comment about similar training given in India.

Comment: Is "technology for all and science for some".

Speaker: This call of science for all has been around for more than 30 years it's still an issue with pertinent programs in the form of students' assessment. At the age of 15 years we are looking at students competencies in sciences. There is also a technology aspect which is relatively a new phenomenon say “computer” technology. However, the technology for all is a new call.

Query: There are fewer students choosing teaching as a first career and there also is a problem of aging population. How about experimenting and taking retired scientists and engineers into mainstream education/ teaching as their second career.

Speaker: I don’t know of any studies done, but it has been ineffective in some cases, I know of at least one school where one new person left at lunch time – a bench chemist and he studied for18 weeks- a course on how to teach and he decided that this was not for him. We have to look at what is happening, how effective can this be. When I started to work 40 years ago there was no need for a teachers training but now it is a requirement.

Query: How can material or methods (teaching aid) be effective in terms of teaching? What are the measures of judging their effectiveness?

Speaker: This is a key issue in science education. It involves issues of readability, concepts, and ready understanding from the text. Does the matter engage students? Tests are not just for assessing students, but also as a follow-up to learn how students are using these materials for learning.

Comment: You might like to add a journal called "Resonance" to your list. It is a reasonably good Indian journal, though not specifically on science education, a large number of scientists contribute to it.

Query: How are Australian aboriginal students included in mainstream science education?

Speaker: This is a source of concern in Australia. Aboriginal students perform poorly, and there are many reasons for it but we lack accurate data. The PISA results showed that when the performance of aboriginal students was removed the remaining students did quite well. There are all sort of reasons for the poor performance, like second language, intermittent schooling, more concern for group knowing than individual knowing, this data if interrogated its never simple.

Query: In countries like U.K there is higher use of computer and other resources of learning as well as to education. Certain groups of students may have more access while others may not. How does this affect science education?

Speaker: Students who are better resourced do better than those students who lack these resources. There can be two possible solutions; use of library and conversation at school.

Trends in Mathematics Education Research: The Example of Algebra Education

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Introduction

This paper surveys some recent trends in mathematics education, by examining some aspects of the evolution of the study of the teaching and learning of algebra. Even though the field of research in mathematics education is small by comparison with the major disciplines in science and the humanities, it is now growing fast and too large to make strong claims about trends and findings, so a narrowing is essential. Algebra education is a good choice because it has been a particularly active field and I can draw on the outcomes of the recent 12th ICMI study on "The Future of the Teaching and Learning of Algebra" (see Stacey, Chick and Kendal, 2004 and Chick, Stacey, Vincent and Vincent, 2001) where many of the world's leading algebra educators worked together to identify major trends and consider the way forward. More importantly, algebra education is a good choice because many of the major concerns of mathematics education as a whole also impact on algebra education.

The paper begins with a short overview placing mathematics education as a discipline within other disciplines, moves on to consider the major recent influences on algebra education, and then demonstrates how mathematics educators analyse problems by looking at several instances of the growth of algebraic thinking. These examples also give a glimpse into the mathematical pedagogical content knowledge that should be part of mathematics teacher education. With experience, many teachers develop an intuition about the difficulties students have and the common errors, but they need help to see the messages about learning and about mathematics that lie behind them.

When adopting a case study methodology in any area of research, it is difficult to make generalisations. In this paper, we are adopting a case study approach to "trends in mathematics education" by looking at a problem in algebra education. I hope that this case study demonstrates at least one generalisation: the power and importance of simultaneously examining the mathematics, the learner and teaching methodologies.

The discipline of mathematics education

I see mathematics education as essentially a practical discipline, where the underlying goal is always to promote better learning of mathematics by students. Of course there are many subtleties of what mathematics should be learned and why, in whose interest is it that students learn, how achievement is measured etc, but the discipline of mathematics education is underpinned by a faith that a good education in mathematics benefits both the individual and society.

Mathematics education as a discipline sits between mathematics on the one hand, and a range of other disciplines (such as psychology, human development, sociology, philosophy, epistemology, pedagogy, curriculum studies, policy studies and science) from which it draws underpinning research findings and concepts. Answering its central question of "how to teach mathematics better" requires understandings from many other disciplines. Mathematics education also draws its research methods from these and other disciplines, and the need to take stock of the plethora of approaches is an ongoing concern. These relationships are illustrated in Figure 1. A characteristic of mathematics education is that political and social considerations play a major role in determining the research questions of mathematics education, although as the field matures, increasingly its research agenda is internally driven. As society changes, as technology changes and as the education system changes, the environment for learning mathematics can be fundamentally altered, which affects the directions of research.

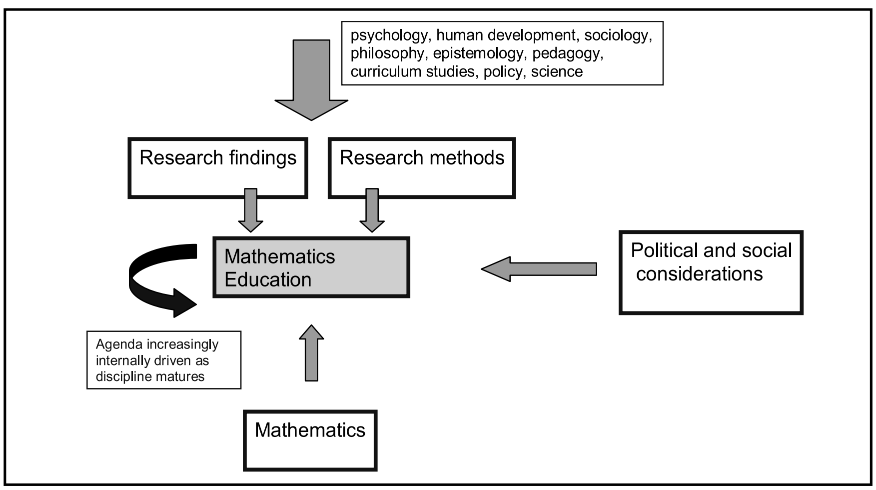


Figure 1. Mathematics education draws upon many other disciplines and concerns although the agenda is increasingly internally driven.

The status of the findings in mathematics education is mixed. Some results describe in a very deep way the basic interaction of the human brain and mathematical ideas. These results are likely to be observable in any society and across time. As the oldest human study, stretching back millennia, mathematics retains an identifiable core of fundamental processes by which it is developed. One example particularly relevant to algebra and in particular to the examples discussed below, is the way in which many concepts have their roots in actions and processes, which become encapsulated as mathematical objects. We see these changes in students' growing conceptions (e.g. of algebraic functions) and we know that teaching needs to ease such transitions. After three decades of work identifying some of these fundamental processes, algebra education can now go forward on a strong base.

In contrast to findings likely to be observable in any society and across time, some findings of mathematics education are insightful and important, but are mostly relevant to a particular situation at a particular time. Studies of the impact of the recent changes to the algebra curriculum in some Western countries, where traditional manipulation was suddenly markedly reduced, are like this. However, much of the best research has something to say of immediate interest, as well as contributing lasting insights.

Mathematics education should, for me, aim to promote better leaning of mathematics for all. Its success should, in the long term, be measured by this criterion. Setting this goal reveals my underlying belief that good mathematics education benefits both society and the individual through its contribution to the economy, science, engineering etc., and through its contribution to the individual. It can empower individuals in every day life, bring them personal fulfilment through studying its beautiful patterns and working on its magnificent problems, and can strengthen more general values such as personal autonomy and the value of applying logical thought to issues. Wolf (2002) provides an interesting analysis of the personal financial benefit of studying mathematics, in the context of a provocative account of the economic benefits of education in general.

Trends in algebra education

Trends in algebra education research, as in other areas of mathematics education, are influenced by factors external and internal to the field. A group of external factors have led to the "massification" of secondary school education, whereby it is now the norm in many countries, that most students complete secondary education, and this education includes algebra. Algebra is seen as a "gateway" to higher mathematics, because it provides the language in which generalisations are expressed. Consequently, having students learn algebra is important for the production of "knowledge-workers" as well as being important for social equity. But algebra is difficult, and instead of being a gateway, it can easily be a wall that blocks students' paths. Mass education thus highlights two challenges: to provide education that is relevant to students, and to provide teaching that is equitable, giving all students an opportunity to advance. We need an algebra with mathematical integrity that is more interesting and meaningful, more related to students' lives (and related to their lives in ways which students themselves recognise) and which is also more learnable. Traditionally, algebra had been mainly seen as symbol manipulation, but most graduates of such curricula have no appreciation of why this knowledge is important. This leads to a reconsideration of the goals of algebra, to identify what are its essential components and to a search for improved teaching methods. In the ICMI study volume, MacGregor (2004) provides a perspective on these issues from the point of view of low achieving students.

The new technologies have also impinged very strongly on algebra education research. As *communication* technologies, these impact on all of education (e.g. distance learning, data from the internet, new means of presentation etc). But as *information* technologies, these impact centrally on the way in which mathematics is done. Mathematics at every level, from the work of the shopkeeper to the mathematician, has always struggled to make calculations easier, and we now have tools that can perform nearly all of the standard routines known by an undergraduate at the press of a button. This provides a serious challenge to existing curriculum: what is the role of the machine and what is the role of pencil-and-paper skill? To answer this question, we need to be very clear about goals for algebra education, about what it means to understand and to develop new pedagogies to meet the new situation. However, it also provides exciting new opportunities for teaching, especially through the possibilities of teaching with multiple representations of algebraic ideas (see Figure 2). Common technology for graphing has made one of the most important changes to date since scientific calculators. In schools where students have access to graphics calculators or computer software for function graphing, they have immediate access to multiple representations of functions, so that they can move readily between the symbolic expression, the table of values and the graph. Importantly, whereas a by-hand graph is a static object, the new graphs are manipulable objects, where rescaling can tailor the graph immediately for different purposes. This has great pedagogic value as well as functional value, assisting students to solve problem more efficiently. Two chapters in the ICMI Study volume (Kieran and Yerushalmy, 2004; Thomas, Monaghan and Pierce, 2004) explore these issues and discuss options in depth. The GNU/Linux software “gnoware” (HBCSE) distributed to all participants of the conference, includes free software with these capabilities.

These two major external social and political considerations (massification and new technology) lead mathematics educators to rethink and research at all three corners of the didactic triangle: what is the core of algebraic activity, what are the most productive teaching approaches and how does the learner respond. If algebra is no longer just symbol manipulation, what is it? This sets an agenda to categorise its problem domains and identify the most fundamental aspects as well as raising questions such as "what does it mean to say that algebra is a language?" At the same time, we consider how teaching might be improved. Suggestions discussed at the 12th ICMI study (Stacey, Chick and Kendal, 2004) can be generally classified as

- By using technology
- By adopting the best approaches from around the world
- By giving students a better start to algebra (Kaput and Lins, 2004)
- Through better teacher education (Doerr, 2004)
- By identifying major points of cognitive challenge from psychology, epistemology, from the history of mathematics, or empirically.

Algebra education research is also impacted by trends that are internal to the educational research community. At a simple level, the growth in international exchange has opened up appreciation of the possibilities for curriculum, teaching and assessment. My observations are that most people begin by thinking that algebra education is something common around the world, and are surprised to see the variations. In fact, the differences are now known to be large on all dimensions – the degree of formalism, the amount of manipulation, the place of functional thinking, the use of technology, the age of introduction etc (Kendal and Stacey, 2004). There are many alternative successful approaches. For example, at a similar age, Russian students may be solving the complicated inequality $\{x : |1 - |1 - x|| < 1/2, x \in \Re\}$ and Australian students may be fitting a straight line graph to a scatterplot of data of the students' arm spans against their heights. Yet these two countries perform at similar overall levels on international tests such as TIMSS (Routitsky and Zammit, 2001).

Important intellectual movements from other disciplines also impact on algebra education. For example, studying the history of mathematical ideas has led to the identification of particular cognitive obstacles for students (e.g. related to the ways in which letters are used), and consequently to teaching approaches that assist students cross the barriers (Puig and Rojano, 2004). On a more theoretical level, the role of algebra as "the language of mathematics" has been studied from the point of view of semiotics (the science of symbols) and linguistics (the science of language) (Drouhard and Teppo, 2004).

On-going reconceptualisation of the core of algebra, of what is most important to teach and to learn has also had an impact on algebra education. For example, in many western countries, it has led to elevating the importance of graphs and functions, and somewhat reducing emphasis on solving and rearranging expressions. The ability to deal with graphs and to have an elementary concept of function are more likely to be seen as "basic" now that complicated symbolic manipulation can be handled by machine in advanced work (including engineering) and also now that easy-to-use

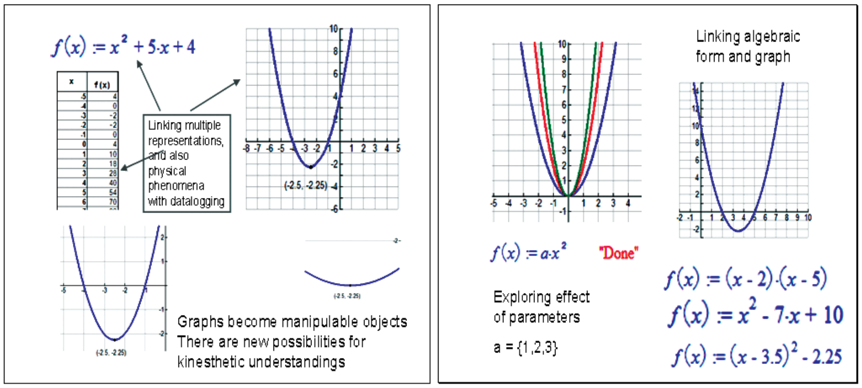


Figure 2. Linking symbolic with graphical and numerical representations

function graphing is available in free or inexpensive programs for computers and hand-held calculators. The study of multiple representations of functions is now very much easier, as illustrated in Figure 2.

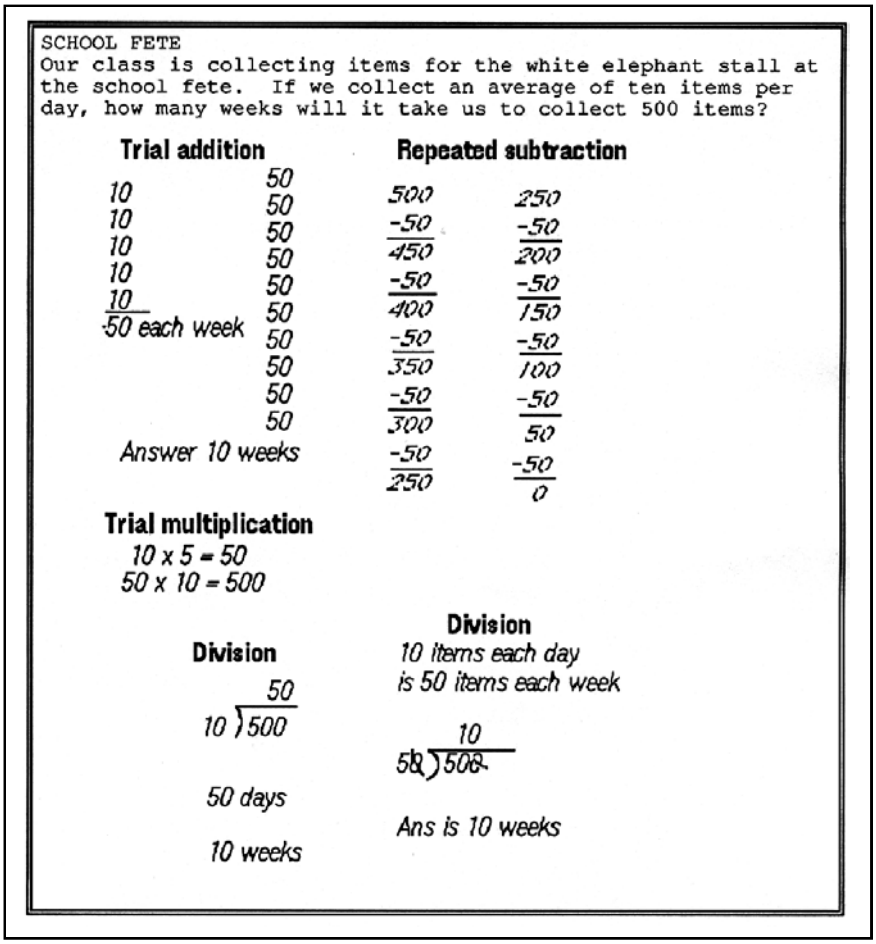
A case study: Shifting from arithmetic to algebraic thinking

In the rest of this paper, I will provide three examples of how mathematics educators are working to develop a firm basis upon which students' algebra experiences can be improved. All of the examples will illustrate the changes that students need to make as they move from learning arithmetic to learning algebra. Only in recent years have mathematics educators documented these changes. The steps that are continuing now are to decide whether these changes actually constitute obstacles for students (or for some students) and to experiment with ways to help students make the transitions. However, there may be other possibilities, such as designing curricula which avoid the need to make difficult transitions for some students, yet still giving them access to worthwhile and useful learning for their adult lives.

Example 1: Algebra requires firm understanding of operations

The first example is a simple one. Figure 3 presents a relatively simple problem which educators would classify as a division problem. However, solutions collected from Grades 5 to 8 (ages about 10 – 13) show that many students do not see this as a division problem. Instead, some solve the problem by trial addition (keep adding 50, or 10, until you reach 500), repeated subtraction (start with a goal of 500 and take away 10 or 50 until you do not need any more donations), trial multiplication (guess how many weeks and test by multiplying), or division. These are all good methods for this isolated problem, but if the methods indicate that a student is not able to conceptualise this problem as a division problem, then there is likely to be a difficulty moving to algebra. The parallel algebra problem may require N items, with d per day: how many weeks? Now there is no possibility of trial arithmetic (d+d+…d = N), or repeated subtraction (N -d-d…-d = 0), or trial multiplication (d x ? = N).

This problem can only be solved algebraically by seeing it as a division problem: the number of weeks is N/5d; there is no alternative. Students with a limited experience of arithmetic operations cannot do algebra. Whereas there are many paths in arithmetic to solving an individual problem and understanding of basic operations (e.g. counting, addition, subtraction) can often compensate for lack of understanding of multiplication or division, this is not the case in algebra. Immature understanding of arithmetic operations hinders students trying to learn algebra. In fact, it often also hinders students in their work with fractions and decimals, which require a similarly more sophisticated understanding of operations than the whole number example in Figure 3. Stacey and MacGregor (1997) and MacGregor


SCHOOL FETE
Our class is collecting items for the white elephant stall at the school fete. If we collect an average of ten items per day, how many weeks will it take us to collect 500 items?

Trial addition
10
10
10
10
10
50 each week
50 50 50 50 50 50 50 50 50 50
Answer 10 weeks

Repeated subtraction
500 −50 450 −50 400 −50 350 −50 300 −50 250
250 −50 200 −50 150 −50 100 −50 50 −50 0

Trial multiplication
10 x 5 = 50
50 x 10 = 500

Division
10)500 = 50
50 days
10 weeks

Division
10 items each day
is 50 items each week
50)500 = 10
Ans is 10 weeks

Figure 3. A division problem showing solutions using other operations

and Stacey (1999) present other examples and discuss other examples of the transition to algebra from arithmetic.

Example 2: Reconceptualising arithmetic to stress its algebraic nature

The next example demonstrates that algebra requires a structural understanding of mathematical statements, and that this can be developed in the context of arithmetic to prepare students for algebra (Stephens and Fujii, 2002). Structural understanding is sometimes called relational understanding. An early introduction to algebra need not start with introducing symbols (e.g. $x + x = 2x$) but can start years earlier through an enriched approach to arithmetic, where students understanding is more firmly based. Three stages of students' thinking will be illustrated[1] from an interview task recently used in as yet unpublished work by Max Stephens and Toshiakira Fujii.

> *Fill in the boxes in three different ways. What is the relationship between the numbers in the boxes? Is the relationship always true? Why?*
>
> $23 + \square = 26 + \square$

The first student fills in the first box with 3, and comments that the second box can be anything. This student does not understand that both sides of an equation are equal (an essential prerequisite for algebra) but sees the statement as an instruction to carry out a calculation: 23 + 3 gives 26 ("=26") and then you can add something else to the 26. This unsymmetric meaning for = , as an instruction to carry out an operation indicated on one side to get an answer indicated on the other, has been identified in the literature as an important obstacle for students, but also one which can be overcome by appropriate experiences in early years. Some of the experiences are very simple, such as presenting students with questions such as $\square = 2+3$ as well as $2+3 = \square$.

[1] The final two student answers are derived from student interviews by Stephens and Fujii but have been adapted for presentation purposes so that they relate to one example. The first answer shows a well known phenomenon of interpretation of equals sign (see for example, Stacey and MacGregor, 1997; MacGregor and Stacey, 1999) and has been constructed for this presentation.

The second student fills the first box with 15 and the second box with 12, and can also give other correct pairs, but always answers "why" with calculations such as 23 + 15 = 38 and 26 + 12 = 38. Although this student understanding the symmetric equals, he or she is still relying on "procedural" thinking – calculating answers rather than thinking about the relationships between them.

The third student demonstrates structural thinking with his or her answer: "*15 [in the first box] and 12 [in the second box]. Comparing 23 and 26, since 26 is three more, so 15 has to become three less"* (Stephens and Fujii, personal communication). This answer reveals structural thinking. The student is not calculating answers, but is working with the relationship directly. The key feature of structural thinking here is making the link between

- the observation of 3 as the difference between 26 and 23 and
- 3 as the difference between the numbers in the boxes.

This is different to the thinking of the second student who finds a lot of pairs of numbers that can go into the boxes, e.g. (15 and 12), (3 and 0), (10 and 7), (23 and 20) and then observes the empirical fact that there happens to be a difference of 3 in the number pairs that work. The second student may well observe and comment on this pattern in the numbers that has been found, but the third student sees the reason.

The early algebra movement (Kaput and Lins, 2004) is not an attempt to introduce symbol manipulation to younger and younger students, but rather an attempt to reform and update the teaching of arithmetic in a way that stresses its algebraic character. Some of the work by Subramaniam and colleagues at the Homi Bhabha Centre (see, for example, Subramaniam,

2004) provides an excellent example of how we may move forward on this agenda.

The distinction between procedural and structural thinking, which is demonstrated in this example and also in the next in a different way, is one that is supported by some empirical evidence, but it derives greater importance because of the role which this and associated ideas play in theories of the creation of mathematical concepts, as noted above. Empirical evidence can demonstrate students who are at different points along the journey from a procedural to a structural understanding of number or algebra equations, for example. Mathematics educators have also sought parallel changes in the history of mathematics (e.g. Puig and Rojano, 2004). Theory builders, such as Sfard (1991) and Dubinsky (Dubinsky and McDonald, 2001) see mathematical objects as having their psychological origins in mathematical processes (though a variety of mechanisms), whilst Tall and colleagues (Tall et. al, 2000) stress the importance of being able to switch between thinking about a mathematical object structurally (e.g. looking at the whole relationship $23 + \square = 26 + \square$) and procedurally (i.e. going back to interpret $23 + \square$ as an instruction to add, albeit an unknown quantity). These are interesting theories, which aim to connect disparate observations from different areas of mathematics, but which have special interest for algebra education.

Example 3: Arithmetic or algebraic thinking in solving equations.

The previous example illustrated transitions in thinking that are required in students' understanding of arithmetic statements to prepare for algebra. Transitions with a related character are also required in learning to solve equations[2]. Some of the difficulty that students have in using algebra to solve problems can be explained by the difficulty that they have in reconciling the methods of solving problems in arithmetic with the new reasoning patterns that are required to solve problems using algebraic equations. Charbonneau (1996) quotes a description of the algebraic method of problem solving by Reneì Descartes in "La geìometrie" of 1637 written in the context of his new Cartesian geometry:

> *If, then, we wish to solve any problem, we first suppose the solution already effected, and give names to all the lines that seem needful for its construction - to those that are unknown as well as to those that are known.Then, making no distinction between known and unknown lines, we must unravel the difficulty in any way that shows most naturally the relations between these lines, until we find it possible to express a single quantity in two ways. This will constitute an equation since the terms of one of these two expressions are together equal to the terms of the other.*

In this quotation, Descartes points out significant differences between solving a problem with algebra and solving a problem by arithmetic: that the problem is first supposed solved; that names are given to all unknown quantities and then no distinction is made between knowns and unknowns; that the relations between the known and unknowns are found and a single quantity is expressed in two ways, giving an equation. It is very interesting to see this description of a standard piece of school mathematics by a great mathematician, written less than 400 years ago. It identifies differences between solving problems using algebraic equations and using arithmetic

[1] The analysis presented in this section has previously appeared in Stacey (2002).

that modern research has demonstrated are difficulties for children. For students to come to learn the algebraic ways of thinking, they need a careful introduction which helps them identify differences between the reasoning used for solving problems with algebra or arithmetic.

Many students continue to use the reasoning patterns appropriate to arithmetic when they try to solve problems using algebra. In particular, they expect that problems are solved by direct calculating. Investigations by our Melbourne team and others (e.g. Bednarz and Janvier, 1996; Kieran, 1992; Stacey and MacGregor, 2000) show that this belief, which is firmly rooted in everyday experience and elementary grade mathematics, accounts for much of the difficulty experienced by students in their early algebra learning. The compulsion to calculate can prevent students looking for, selecting and naming the appropriate unknown or unknowns, and can prevent them from writing an algebraic equation. It prevents some students from attempting to use algebra, and deflects others away from an algebraic method that they have started.Some of the differences between the reasoning required for solving problems arithmetically and algebraically using equations are shown in Figure 4.These differences are illustrated with the two car rental problems in Figure 5, which shows a standard solution by algebra and a solution by arithmetic.

Both problems can also be solved in other ways (e.g. guess-check-improve or graphically) and the recognition of this is a good feature of current Australian curricula. The arithmetic solution for RENTAL COST begins with a calculation. The known quantities (total cost and flat charge) are used to directly calculate another quantity, the money that can be spent on the “per km” charge.

Solving a problem with arithmetic	Solving a problem with algebra
Operating with and on known quantities to calculate unknown quantities.	Operating with and on known and unknown quantities.
Solution proceeds along a chain of successive calculations, working progressively towards the answer.	Solution proceeds along a chain of logically linked equalities or inequalities.
Unknowns transient, representing intermediate stages.	Unknown(s) identified and stable throughout the problem.
Equation (if any) is interpreted as a formula for calculating answers or narrative of what happened to a number.	Equation interpreted as formula, narrative or a description of relationships between quantities.
Intermediate quantities have a ready interpretation	Intermediate quantities may not have a ready interpretation.

Figure 4. Some contrasts between the reasoning involved in solving problems using arithmetic and algebra (adapted from Stacey and MacGregor, 2000)

This newly known quantity now permits another unknown quantity to be calculated (the number of kms which can be driven for that "per km" charge). The solution has proceeded via a series of calculations, where known quantities are combined to progress towards the answer. When we have interviewed students about this (Stacey and MacGregor, 2000), some see two transient "unknowns" which successively become known (the money available for the "per km" charge, then the number of kilometres). The intermediate quantities that have been calculated have a real world interpretation (e.g. money to spend on the "per km" charge) and logical reasoning about these quantities guides the solution process.

In contrast, the algebraic solution starts with identifying one unknown (the number of kilometres driven) at the beginning and this remains with the same meaning throughout the solution. It is first used in a description of the problem situation: $0.20x + 100 = 240$.

This description becomes the first of a chain of logically linked equations. Many students who have difficulty setting up an equation do not appreciate that it is *only* a description of the relationships that they need: instead they try to write the answer in the first equation that they construct e.g. as $x = (240 - 100) \div 0.20$ (more commonly dividing by 20 instead, or multiplying by 5 with the reasoning given in the alternative arithmetic solution in Figure 5) or even putting in some symbols to get $x = (a-b)/c$ *or* $(a-b) \times 5$ (Stacey and MacGregor, 2000). In other words, they try to solve the problem arithmetically in order to write the equation, instead of writing the equation in order to solve the problem by algebra. Finally, in contrast to the arithmetic solution of RENTAL COST, the real world meanings of the quantities and relationships are of no significance to the solution process. The arithmetic and algebraic solutions for RENTAL COMPARISON demonstrate the same features although, as discussed below, it is a harder problem to solve. (I note that the problems may be done more elegantly using inequalities instead of equations. I have used equations here for simplicity.).

One important difference between the two problems in Figure 5 is that a problem such as RENTAL COST is much easier to solve without algebra than the other problem. Many children in elementary school can understand what to do quite easily, although they may have trouble with the calculation (dividing by twenty cents). RENTAL COMPARISON is much harder to solve without algebra and many adults cannot do it. There is more information to process and the quantities which are to be operated upon (the excess fixed fee compared with the excess cost per kilometre) are awkward to conceptualise and name.

RENTAL COST	RENTAL COMPARISON
To rent a car from Tiger costs \$100 per day and 20 cents per km. How far can I drive, if the most I can afford to pay is \$240?	To rent a car from Tiger costs \$100 per day and 20 cents per km. To rent a car from Kangaroo costs \$120 per day and 15 cents per km. When is Tiger cheaper?
Solution by algebra Let x be the number of kilometres that can be driven. $0.20x + 100 = 240$ $0.20x = 140$ $x = 140 \div 0.20$ $= 700$ <u>I can drive up to 700 km.</u>	**Solution by algebra** Let x be the number of kilometres driven when costs are equal. $0.20x + 100 = 0.15x + 120$ $0.20x - 0.15x = 120 – 100$ $0.05x = 20$ $x = 20 \div 0.05$ $= 400$ <u>Tiger is cheaper if I drive less than 400 km.</u>
Solution by arithmetic \$240 – \$100 = \$140 (money to spend on kilometre charge). Cost per km is \$0.20. Number of kilometres that can be driven = money available ÷ cost per km = \$140 ÷ \$0.20 = 700. <u>I can drive up to 700 km</u>. [Alternative avoiding division by number less than one: 5 km per dollar, so 140 x 5 km for \$140]	**Solution by arithmetic** Kangaroo costs \$20 more for the fixed fee. Tiger costs 5 cents more per km, so every 20 km costs \$1 more. So the additional mileage fee for Tiger is less than the additional \$20 fixed fee for Kangaroo until I have driven 400 km. <u>It is cheaper to rent from Tiger if I drive less than 400 km.</u>

Figure 5. Two problems with the mathematical structure of a linear equation

These difficulties are reflected in the occurrence of the unknown on both sides of the corresponding equation in the second row of Figure 5 for RENTAL COMPARISON. Note that RENTAL COST has only one occurrence of the unknown. Many researchers in algebra education now ascribe these differences in difficulty to the need to operate with the unknown quantities. (Bednarz and Janvier, 1996; Filloy and Rojano, 1989; Kieran, 1992).

The arithmetic solution in Figure 5 is difficult to arrive at – this is because the more direct path of comparison is blocked because the number of kilometres is unknown. The direct costs for both rental schemes cannot be compared without operating with the unknown kilometre charge.

Because solving problems with one occurrence of the unknown does not require operating with the unknown but only with known quantities, some researchers (e.g. Filloy and Rojano, 1989) use the term *arithmetic equations* to describe equations where x appears on only one side (in our example $0.20x + 100 = 240$). They reserve the term *algebraic equations* for equations where x is on both sides (in our example, $0.20x + 100 = 0.15x + 120$). In this sense, solutions to RENTAL COST involve arithmetic thinking (regardless of whether letters are used) whereas most solutions to RENTAL COMPARISON involve algebraic thinking. Operating with the unknown is well-established as a technical difficulty and conceptual for some students and, when there is no readily available back-up strategy, it becomes a major cognitive obstacle (Kieran 1992; Stacey and MacGregor, 1997).

The problems above demonstrate that some linear equation problem situations - those relating to equations with the unknown on only one side - are relatively easy to solve without algebra, but others - relating to equations with the unknown on both sides - require hard thinking if algebra is not used. The advantage of the standard algebraic solution technique for linear equations is that it turns both classes of problems into routine tasks. It is one of the most elementary demonstrations of the power of algebra, which ideally should be appreciated by junior secondary students, but is often missed.

Drawing the examples together

The three examples above illustrate some aspects of the work of mathematics education researchers in analysing didactic situations. At least three components need to be considered. From a curriculum perspective, it is important to centre work on mathematical ideas that are key to developing a full understanding of mathematics and a numerate population. So it is important to decide what are the key ideas of algebra, conceived of as a broad area of the curriculum and judged as a part of mathematical cultural heritage and a utilitarian education. Simultaneously, mathematics educators must discover an appreciation of mathematics looked at from beneath+ – from the point of view of a learner. In this way, the perspective on the subject from the top (the curriculum component) needs to be juxtaposed with the perspective from underneath, from the point of view of a learner with developing cognitive capacity, language skills, world experience etc as well as a limited mathematical understanding. Moreover, mathematics educators have to develop this viewpoint so that they can see mathematics from the points of view of students of many different abilities and life experiences. The third component to consider alongside the curriculum content and the learners' perspectives is the teaching approach (see, for example, Bednarz, Kieran and Lee, 1996). What students are taught, even in subtle and indirect ways, and in other parts of mathematics can affect their potential to work well in algebra. Assembling all of the evidence from these varied sources (curriculum, learners, and teaching) is essential in designing improved teaching approaches, and being able to predict the consequences of the many decisions involved in such a complex undertaking.

Research into algebra education is a good example of mathematics education at work. It is a lively field aiming to engage with social needs and intellectual advances. Its success should be judged by the extent to which it can promote algebra as a lively, engaging and worthwhile subject for an increasingly large number of students. It is important that algebra is a gateway to higher mathematics, as well as a useful way of seeing the world, not just a wall that blocks the progress of many students.

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Discussion on the presentation

Query: Do difficulties amongst children's poor performance at primary levels hamper their future scope and interest in maths? Sometimes students perform poorly in algebra, why not allow students to make choices later? Should they then be exposed to mathematics only at higher or secondary level?

Speaker: While taking the example of algebra as a subject of mathematics, it is an important question of equity or fairness for all students. It is important that we don't cut too many students off from the possibility of higher education very early by saying that these students are not good in algebra now, so we are going to stop you here. We need to make sure all students get a fair start, so that we don't make pre-mature decisions about who has the capacity to go for university and who doesn't and that some have higher opportunity to learn advanced mathematics.

Query: What is the place of culture in teaching mathematics? How can mathematics be teachable according to cultural differences or where cultures dominate and there are also prevalent gender issues in education? How do we use technology in teaching- learning of mathematics when there is lack of access to even electricity and similar resources?

Speaker: Technology is really a question of divide around the world. Some students cannot afford to buy a calculator, while in a rich country like Australia; students who cannot afford a computer can have a calculator. Thus some countries will have to wait on the technology front in mathematics education. One needs to look into as economic decisions also. It is possible that some materials, such as calculators be made available to the teachers, so that they can teach their uses. It is not essential that every child gets access to computers in mathematics.

Answering the culture question and its relation to mathematics education, in the Australian culture, which is a very pragmatic culture- there are lots of data and graphs in mathematics education. Whereas Russian students have symbolic algebra. This could be one of the cultural differences. Children in India as I saw in some mathematics classroom were very different from those in Australia, where it would be very difficult to make children sit for long class room hours.

In the Australian education system, I think we have now eliminated the problem of girls and mathematics in school. There is a lot of attention paid to giving meaning to variables and to the whole structure and not presenting just abstract symbols that have to be manipulated. There are no achievement differences between girls and boys though there do still remain participation differences in school at the very end of school where mathematics is compulsorily.

Query: Most schools in India have centralized curriculum system, teachers are not oriented to the newer approaches to teach, and since the number of students is also high teachers take short cuts for problem solving (manipulating the solution process) while teaching mathematics. How can it be overcome? How can newer approach motivate teachers to experiment and how can such approaches be brought about in such a situation?

Speaker: It is the same anywhere in the world and with the challenges in India with an enormous population growing fast, teacher education within universities in India needs to change. We need to begin to establish teachers' education in the discipline of mathematics/science, as a significant part of the preparation of teachers and conceptualize, what it is a teacher needs to know while teaching the subject in school. In a direct way such changes would certainly help teachers, as well as students in improving mathematics education

Trends In Technology Education Research

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The concept of 'didactics'

In the *Routledge International Companion to Education* a separate chapter was dedicated to 'didactics'. The author, Gundem, explained that the term 'didactics' in the Anglo-Saxon languages has a negative connotation, because it indicates rigid prescriptions for teaching. But in other languages, such as French and German it has a much more positive meaning. 'Didactique' or 'Didaktik' stands for the systematic and scientific reflection on teaching practice, leading to knowledge that can be used by teachers to improve teaching and learning (Gundem 2000). Teachers see 'didactics' as a natural component in their training and try to apply it in their work, and the research community has accepted it as a serious research field for many school subjects. In physics education in the Netherlands, teachers have often been involved in research projects. Those projects are often a combination of research and development work (in business circles this would be indicated as R&D). So it appears to be possible to give content to such a concept as 'Didaktik', 'didactiek' or 'didactique' or whatever it may be called (from now on the term 'didactics' will be used, but the reader should keep in mind that this is not meant in the Anglo-Saxon mode). The idea that 'didactics' provides a scientific basis for teaching should be reflected in the research agenda for 'didactics'.

The agenda of 'didactics'

The agenda of 'didactics' should reflect the needs of teachers, as researchers should address them. Gundem presented such an agenda. In this paper that agenda has been adapted to become the following (also see De Vries 2000):

(1) What are goals and contents for teaching (and why are these to be regarded as such)?

(2) To whom (pupils and students) and by whom (teachers) is this content taught? What are their characteristics (knowledge, experience, attitudes, etc.)?

(3) How can teaching-and-learning situations be realised to pass on the identified content (see 1) to the identified target group by the identified people (see 2)?

Several authors have stated a desirable research agenda for technology education. Lewis (1999) and Petrina (1998) have tried to bring together such agendas. Although differently phrased, their ideas do not differ fundamentally. Both in fact present a research elaboration of the 'didactics' agenda as has been used in this paper that can be summarised as follows:

(1) What and why to teach and learn about technology?

- **Who defines goals for technology education and what goals are defined?**
- **How can technological literacy as a goal for technology education be defined?**
- **What is the nature and role of knowledge and creativity in technology education?**

(2) To whom and by whom to teach and learn about technology?

- **Who participates in technology education (e.g. pupils, students, and teachers)?**
- **What are their preconceptions and concepts of technology?**
- **What subcultures are there (e.g. genders)?**

(3) How to teach and learn about technology?

- **How was technology taught in the past and in what context?**
- **How do curriculum changes take place?**
- **How does curriculum integration take place (relate technology to other school subjects and to the outside world)**

This list only partially coincides with the list of important issues for technology education that Wicklein and Hill (1996) found among teachers and teacher educators. They mention: funding, academic content, program vitality (position in the school curriculum), leadership, research as a basis for teaching practice, teacher supply, identity of technology education, and integration in the total school curriculum. Of these issues some appear in the research agenda that was based on Lewis and Petrina, but some do not. Evidently there is a difference between what researchers and what teachers see and relevant issues for technology education. Only when researchers and practitioners (teachers) can agree on research topics, a fruitful transfer from research to practice will become feasible. In this paper the research side will be explored: what issues were covered in actual research studies? An analysis will be offered that focuses on the extent to which the agenda of 'didactics' has been addressed in the research practice of the past decade or so. Then we can compare this with the issues that were mentioned as relevant by teachers.

Existing analyses of research output in technology education

In 1997, Karen Zuga published an analysis of research output in the period 1987-1993. She used professional journals and abstract databases to see what issues had been addressed and what research methodologies had been used. Her conclusions were striking. A large majority of research in technology education appeared to be concerned with curriculum content (Zuga 1997). Very little research had been concerned with people (pupils, students, and teachers). Most research studies had relied on descriptive statistics and in only few cases a more interpretative methodology had been used. Finally, only very few studies dealt with the effectiveness of technology education: do we really realise what we promise? And we do promise a lot in technology education: it will make pupils technologically literate, stimulate their creative abilities, help them learn to co-operate, make informed decisions, become critical citizens, etc. But do we have any evidence that we accomplish all that, or even part of it? The proceedings of the PATT-9 conference, that was held in Indianapolis, USA, in 1999, entitled 'Impacts of Technology Education' indicates the lack of empirical evidence that we are faced with when we ask ourselves that question (Custer 1999 and De Vries 1999). That is directly related to the lack of well-based assessment tools that was revealed in the Proceedings of the PATT-8 conference, held in The Hague, Netherlands, in the year before. By now we know that paper-and-pencil tests are not enough, and we have ideas about alternatives, such as portfolios, but we do now have much research on the effectiveness and efficiency of those alternatives.

Evidently there is still a lot to be done here (Mottier 1997). Zuga's research in several respects confirmed a previous study by Foster (1992). His conclusions were based on the topics that he found among USA graduate theses in technology education. He found that most common topics for graduate research were program/project evaluation, instructional methods and strategies, workforce analyses and curriculum development: not in the sense of empirical research into classroom practice, but in the sense of descriptive data collection surveys. As this study by Foster is a bit different from other studies – including the one presented in this paper – because it uses unpublished students' work, we would rather compare our own results with Zuga's study than with Foster's.

In 1998 a second analysis of past technology education research output came out, namely one by Steven Petrina. He had limited his data to the 1989-1997 issues of the Journal for Technology Education that is published in the USA. Several of Zuga's conclusions were confirmed in Petrina's study. Again the findings indicated that most research dealt with curriculum and descriptive statistics were dominant as a research methodology. Besides that Petrina found that many studies lacked a theoretical framework (probably because they did not look for more interpretative ways of discussing the data) and few studies dealt with the practice of teaching and learning technology (Petrina 1998).

Both studies are limited in that they mainly deal with research in the USA. It would be worthwhile to see if the re-sults can be confirmed by looking at other countries. That is possible by looking at other data sources. In this paper we will try to get an insight into a broader international scope by taking the International Journal of Technology and Design Education as our database.

A new analysis with a broader international scope

The International Journal of Technology and Design Education is an international scholarly journal that, from Vol. 4 onwards, has been published by Kluwer Academic Publishers in the Netherlands. It is distributed in many countries worldwide. It is certainly one of the leading international journals for technology education research. Other scholarly journals for technology education - the *Journal for Technology Education* that was used by Petrina, and the *Journal for Technology Studies* that is published by Epsilon Pi Tau, a fraternity - are USA-based and have a bias towards the USA in terms of authors and editorial board. The International Jour-nal of Technology and Design Education for many years was edited by Edgar Jenkins from Leeds University, UK. He was responsible for the Volumes 4 through 10 (1994-2000) and has really made the journal into what it is now. To get the journal off the ground, Jenkins of course used several of his contacts in the UK and perhaps this resulted in a slight bias towards that country. In January 2000 the author of this paper took over his position. The internationalisation that Jenkins had already started quite effectively was further enhanced and now there is a fairly worldwide representation in the board of editors. Alas this is not yet reflected in the articles. In the volumes that are analysed in this article, more than 85% of the articles come from Australia, New Zealand, Canada, the UK and the USA. Table 1 shows the distribution in more detail.

It is clear that the IJTDE (from now on this abbreviation will be used to indicate the journal) is also biased in terms of author's countries. But the spread is certainly 'better' (nothing against overtly US oriented journals

Table 1. Distribution of articles according to author's countries in Vol. 4-10 (1994-2000)

Country of author	Number of articles from this country	Country of author	Number of articles from this country
UK	33	France	02
Canada	22	Netherlands	02
Australia	13	Hong Kong	02
New Zealand	06	Rep. Of South Africa	02
USA	13	Finland	01
Israel	04	Ireland	01
Germany	03		
Total = 104			

with excellent academic content!) compared to the other journals that were mentioned above. At the same time it is evident that there is still quite a challenge here for the new editor.

So again the analysis of research output will be limited. Yet it nicely complements the existing analyses: in terms of the time period it commences where Zuga's analysis ended (in 1994), and in terms of countries covered it substantially adds to Petrina's analysis who in terms of time period overlaps with our new analysis (Petrina: 1989-1997, De Vries: 1994-2000). So if our results deviate from those in the existing studies we have to consider both the broader international scope and the possible changes over time.

Approach for the new analysis

The articles in Volumes 4-10 in the IJTDE cover a wide range of topics. How can we get an impression of the extent to which they address the practitioners' (teachers') needs? To reach that goal we will refer to the 'didactics' agenda that was discussed earlier. All articles will be divided over the three main parts of the 'didactics' agenda: (1) what and why, (2) to and by whom and (3) how to educate about technology. More precisely, we will use the following categorisation:

Under (1) we will put articles that deal strictly with the curriculum in terms of intended outcomes and 'official' content (as described in policy documents and syllabi) and - related to that - with the nature of technology and technology education as derived from theoretical considerations.

Under (2) we will put articles that inform us about the characteristics of teachers and learners, independent of the curriculum.

Under (3) we will put all articles that study the practice of teaching and learning in an empirical way (the realised curriculum).

As a next step, for each category all articles will be divided into categories that represent the target group of the article. In other words: who is supposed to take action, based on the research output? Sometimes the author explicitly indicates that, in other cases we will make our own judgement. Thereby we will particularly watch if the article could be useful for teachers. After all, our main interest was to search for bridges between research and educational practice.

Results of the analysis

In almost all cases it was unproblematic to put the articles in one of the three chosen categories (perhaps only 2 or 3 articles out of our 99 article sample were somewhat ambiguous). Table 2 displays the result of this first step of our analysis.

Table 2. Distribution of articles according to three categories of the 'didactics' agenda

Topic on the 'didactics' agenda	Number of articles in that category
(1) what and why	58
(2) to and by whom	11
(3) how	30
Total	**99**

* NB: the total number of articles is less than the total number of authors in Table 1, because some articles were co-authored by colleagues from different countries.

This table to some extent confirms Zuga's and Petrina's findings of the bias towards curriculum content as the focus of most research studies. Yet in our sample, it is not much more than 50%. A considerable number of studies deal with educati-onal practice, which in Petrina's study was an almost absent category. Of the 13 studies by USA authors 10 were concerned with curriculum content. Perhaps that explains the difference between our and Petrina's findings: a lack of interest in empirical research into teaching practice may well be a USA problem more than an international problem, unless this interest only recently emerged (and thus would not yet be in Zuga's and Petrina's samples.

And indeed, if we look at the year of publication of the empirical studies in the categories (2) and (3) we see that many of those were published in recent years (for category (2) 5 out of 11 articles appeared in the Volumes

9 and 10; and for category (3) 8 out of 30 articles appeared in Vol. 10). Evidently the amount of empirical studies into people and practice, rather than into desirable and intended curriculum content, increases. Perhaps Zuga's alarming article has had some result, at least internationally.

Table 3. Topics that were covered in each of the three categories of articles

Category	Topics	Number of articles
(1) what and why	design/problem solving	10
	values	10
	national curriculum	10
	personal development	6
	philosophical studies	6
	identity of technology education	6
	relationship with science	2
	progress in technology education	2
	CAD/graphics	2
	research agenda	2
	language in technology education	1
	curriculum construction	1
	construction kits	1
(2) to and by whom	teachers' concepts and attitudes	7
	pupils' concepts and attitudes	4
(3) how	design/problem solving	13
	tasks-skills relationships	5
	teacher education	4
	reasoning/concept learning	3
	assessment tools	3
	practical conditions	1
	continuous learning	1

To get some impression of the content of the articles in the three categories, Table 3 presents the topics that were covered. Although most articles touch upon more than one topic, for each of the articles the main topic that was dealt with was selected.

The table gives an indication of some ‘hot’ topics in technology education research. In particular, design and problem solving are quite popular among researchers. But also values and pupils’ and teachers’ concepts and attitudes are well represented among the research topics. The articles that present the national curriculum in various countries are a third group of substantial size. Finally there is a group of articles that deal with the identity of technology and technology education and its relationship with science. Evidently the discussions about the questions ‘what is technology’ and ‘what is technology education’ do not yet belong to the past.

Do these topics relate to the practical needs of teachers? Evidently part of these do not, or do only indirectly. It does not immediately affect teaching practice when a teacher gets to know about the curriculum in a country that is not his or her own. Indirectly it might be a resource of ideas for what could be done, but it does not directly help a teacher in changing his or her teaching practice. To some extent the same holds for reflections on the nature of technology and technology education. These too seem to be more relevant for curriculum developers than for classroom teachers. But the first two groups - about design/problem solving and values/concepts/attitudes - might be of direct interest for a teacher, depending on how the article was written.

Now we move towards the next step: what target groups were addressed by the articles? For the second and third category in the ‘didactics’ agenda this does not cause real problems. In many cases the author himself or herself states, or at least hints at a target audience. Only for the first category, it is often difficult to see whom the author would like to influence by the article. As already stated above, the article might be useful for a teacher who looks for inspiration for new teaching content. Information about pupils' concepts and attitudes can make teachers aware of the need to take into account such ideas when preparing teaching-and-learning situations so that they enable pupils to reconstruct their ideas. Here we can already remark, that strikingly enough the constructivist approach that gained strongly in popularity in science education, in the technology research sample is almost totally absent. In other words: we talk a lot about concepts to be taught (like the concept of 'systems'), but we do not know if pupils already hold 'intuitive (pre-) concepts (do they regard a dish washer as a system that takes input and converts it into output, or do they see it as a collection of nuts and bolts?) and how we can change these. That knowledge would be important both for curriculum developers and for teachers. Table 4 displays the target groups of the articles in the three categories.

As stated above, the numbers for category (1) are less certain than for the other two categories. Most articles seem to be relevant in the first place to curriculum developers and policy makers who have to decide on the position and nature of technology education in the total school curriculum. Teachers might also use such articles as inspiration sources, but seldom are they (more or less) directly addressed. The articles that seem to be most interesting for teachers are those that deal with the practice of teaching and learning, as could be expected. All in all these are not a great number of articles in the total collection that we have investigated.

Table 4. Target groups in articles per category

Category	Target group	Number of articles*
(1) what and why	curriculum developers	42
	policy makers	16
	teachers	4
	researchers	3
(2) to and by whom	curriculum developers	4
	teacher educators	7
	teachers	1
(3) how	curriculum developers	11
	teacher educators	5
	teachers	16
	researchers	1

* NB: some articles addressed more than one target group.

Discussion and conclusions

The outcomes show that the field of curriculum goals and content (the ‘what and why’) is well covered in the research base that we have investigated. Much less attention has been paid to the field of the teachers’ and learners’ characteristics (the ‘by and to whom’). More than expected from the previous analyses by Zuga and Petrina the field of educational practices (the ‘how’) was addressed in the research base. Many of the topics in each of the fields at first sight seem to be relevant for teachers and relate to the topics that they themselves mentioned in the survey by Wicklein and Hill (1996): academic content, identity of the subject, integration in the school curriculum, and in 2 articles the research as a basis for teaching practice. But in all fields the outcomes are often presented in such a way that teachers are not directly challenged to action. Some of the topics that were mentioned as relevant for educational practice by teachers themselves do not seem to have been addressed at all (funding, program vitality, leadership and teacher supply in the list that Wicklein and Hill found). So the tension between researchers' and teachers' interest that was already expected when we surveyed the 'didactics' research agenda in section 3, was confirmed by the analysis. Now the question is: what consequences should that have? Do we need to force researchers to take teachers' needs as a starting point? Or should teachers be better informed about what is really important for their teaching practice, based on the ideas of researchers? Or can we bring the two parties together and make them play together as in a team? In the final section of this paper we will explore that last-mentioned route.

Some recommendations to train research and practice to work as a team

Evidently there is a need to make a better match between research and the practical needs of teachers. For research that means that the research agenda should be defined in such a way that it addresses the needs of teachers. This can be seen as an equivalent of what happens in quality management in business circles: the product more and more needs to be defined according to the customers' needs. Even special methods were developed to accomplish that such as the Quality Function Deployment (QFD) method that might be interesting for technology education (De Vries 1995). In industry the consequence is often, that designers and engineers involve customers in their work. Customers are asked to state their requirements, whereby designers and engineers try to trigger them by giving hints or possible product functions and features. Sometimes customers are asked to assess design concepts to see if they meet their needs. But the experience with such an approach has made evident that customers' needs can not be followed blindly, because customers often lack expertise about what is possible, or often are unaware of the needs that they really have. Designers and engineers have to help them to make their desires explicit and become acquainted with what can be accomplished technically. Thus designers/ engineers and customers have to make a back-and-forth movement with respect to the requirements for the product that is to be developed. All that could be done in a similar way when putting together a research agenda for technology education. Researchers could make inventories of what teachers themselves say they need in terms of 'didactics' as a basis for their teaching. Teachers may also be involved in setting up research plans. They might even be asked to assist the researcher in analysing the data and discussing the outcomes. Vice versa researchers could suggest important topics to teachers and try to raise awareness of the need to do research on those. That would not only help researchers get a better understanding of how the teachers' needs can be transformed into research topics and methods (analogous to the way customer requirements are transformed into product characteristics in a method like QFD), and at the same time it can create commitment on the part of teachers to make use of the research outcomes. In that respect Benenson (2000), was quite right in his comment that it was a pity that there was only one classroom teacher present at the AAAS Technology Education Research Conference where research agendas were discussed. During that same meeting Bennett (2000), emphasised the need for co-operation between research and practice, and justly so. Of course these ideas are not revolutionary or new, but they do not seem to be common practice yet. Real win-win strategies assume that researchers and teachers work together as a team. The analysis that was presented here, clearly underlines that there is still a need to work on that.

The identity of technology education

The increased attention for the fields of 'to and by whom' and 'how' should not make us forget about the continuous relevance of the field of 'what and why' in teaching about technology. In the list of issues that were considered as important by practitioners (teachers and teacher trainers) as surveyed by Wicklein and Hill (1996) academic content and subject identity were mentioned. Evidently practitioners do realise the need for conceptualising the subject of Technology Education. With respect to that, it was striking that this whole issue seemed almost absent in the research agendas that were drawn by several participants of the AAAS Technology Education Research Conference in 1999 (as shown in Cajas' Introduction to the Proceedings, 2000). In that respect McCormick's (1997) work on the relationship between procedural and conceptual knowledge shows that conceptualising technology for technology education remains of importance.

Here - much more than has been done before – should be learnt from certain academic fields that are concerned with the issue of conceptualising technology, in particular the philosophy of technology and design methodology.

The philosophy of technology according to Mitcham (1994) deals with four ways of conceptualising technology: as artefacts, as knowledge, as process, and as volition. All these are relevant for technology education.

The debates about 'didactics' research in technology education would gain much by drawing from this field. Likewise profit can be made by drawing from the outcomes of design methodology research and reflections. According to Cross (1993) here there are five main areas of attention: the development of design methods, the management of the design process, the structure of design problems, the nature of design activity, and the philosophy of design method. For each of these equivalent considerations can be found with respect to design activities in technology education, and as we have seen, these activities are a 'hot' topic in technology education research.

In previous parts of the paper the relevance of transferring experience from science education research has been mentioned. Altogether this shows that technology education research should be embedded in a network of contacts with related research disciplines. In particular for technology education as a subject with a small or (almost) no tradition this is certainly a prerequisite for becoming a serious research discipline. And that is what practitioners would certainly welcome as a basis for their work in schools, so that in the end our pupils will gain from the results of researchers' efforts.

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Discussion on the presentation

Comment: Interestingly in India and other developing countries there are very active groups who are dealing with concepts like "people's technology, alternative technology, traditional technology, appropriate technology, etc" and at the same time they are also looking at educational systems outside the formal system of education.

Comment: In traditional education in Tanzania, technology education was a subject since 115 years ago, and in the present, it is a school subject for 10-13 year olds. It spans topics such as, agriculture, animal husbandry, food conservation, pest control, water harvesting, tool making, smelting, cloth technology- weaving and dyeing, soap making, decoration making, energy technology- charcoal making, biogas, etc.

Speaker: It is an excellent example of how countries should deal with technology education. But there are same terrible mistakes also. For example in South Africa the textbooks are taken from England and there are no attempts at contextualizing the content. While working with South African teachers in the township I often heard them complain that we cannot teach technology as we do not have computers, machines and other resources. I took them to a local open-air museum and gave them a list of topics from the curriculum, such as, transportation. I asked them to tick those topics and the foundational concepts which could be taught with the help of the available examples. The teachers ticked almost all the topics on the list and realized that it is not only computers and lasers which can be a resource for technology education.

Query: I am involved in informal education, out-of-school education and women's Studies. What is gender specific technology? How can one improvise the use of "gender specific" technology especially in the context of Africa where teaching aids in terms of technology and equipment are limited?

Speaker: Out of school activities are related to gender issues and technology education. Boys and girls have different backgrounds (out of school activities) and these can result in differing attitudes to technology and technology education. One of my studies in the Pupils Attitudes Towards Technology (PATT studies) has shown these differences. There are various other dimensions of gender and technology such as the behaviours of girls and boys in performing technology activities when in groups.

Out of school activities are very important support for the technology curriculum. For example it is difficult to show what happens in industry except maybe through visits or a televised demonstration of the outside world. When there is no technology curriculum the out of school activities or education is even more important.

Query: You have told us about the problems in the formation of a new subject and a new field of research. Can you remark about alternative approaches like having Science, Technology and Society (STS) as a subject in isolation, rather than as a part of science or technology.

Speaker: Lots of technology is presented in context of either science education or teacher training. Technology is often used as an advertisement; a context to make students learn science or it is used to show the application of scientific principles. The process of innovation, or getting from a problem to a solution is ignored. There are certainly good example of STS, but sometimes the “T” Technology is crushed in between the two “S” i.e. Science and Society.

The Impact of Idealist and Relativist Philosophies of Science on Contemporary Science Education Research

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Introduction

Philosophies of science have an impact on both empirical and normative science education research. How one understands science, both its methodology and the truth status of its claims, will affect what educational issues are deemed important to research, and what proposals for the 'reform' of curriculum, teaching methods, and assessment are advanced. Reasonably enough, views about good or 'authentic' science teaching and learning will be informed by views about what constitutes good science.

The impact of philosophical views on educational research and practice has been extensively studied. The influence of Positivism on science education is well documented - even if there has been confusion about what constitutes positivism. Similarly the impact of 'Kuhnianism' has been studied. Studies have been done on the way in which Islamic philosophy of science affects science education and shapes research questions in Islamic countries (Hoodbhoy 1991, Loo 1996). There are comparable studies on the impact of Hindu philosophy of science on science teaching in Hindu cultures (Nanda 2003). There have been enlightening historical studies of the impact of National Socialist philosophy of science on science teaching and research during Hitler's Third Reich (Beyerchen 1977); the impact of Marxist philosophy of science on the conduct and 'reform' of Soviet science education has been studied (Graham 1973, 1993); and there have been studies of the influence of Thomistic philosophy of science on science programmes in Catholic school systems and countries (Barrett 1961, Lonergan 1993). In all of these cases it is obvious that the 'goodness' or 'badness' of the influence is in large part dependent on the quality of the philosophy doing the influencing; this is abundantly clear in the case of normative studies, ones that chart 'reform' directions and outline goals and aims of good science teaching.

Over the past few decades more and more science educators and researchers have aligned themselves with constructivist post-Kuhnian idealist and relativist philosophical positions – some being merely post-positivist, other going all the way and becoming post-modernist. Getting an accurate and comprehensive picture of the impact of these idealist and philosophies on science education research is difficult and beyond the scope of this paper.[1] However a recent book by Peter Fensham - *Defining an Identity* (Fensham 2004) – provides a rich source of material for at least a partial, if depressing, answer to the question.

Peter Fensham's study: Defining an identity

Peter Fensham, was the foundation professor of science education at Monash

[1] The amount of research and publications in the field over just the past three decades is enormous. There are at least six major international science education research journals publishing perhaps 300 articles per year, additionally there are numerous national and teacher-focused journals. The decade-old Helga Pfundt and Reinders Duit's 4th edition of the *Students' Alternative Frameworks and Science Education* bibliography contains 4,000 entries (Pfundt & Duit 1994).

University in Australia; he is a prominent figure in international science education, whose work has been the subject of a recent anthology (Cross 2003). His *Defining an Identity* is based on interviews with 79 leading science educators from 16 countries (48 being from the USA, Canada, Australia and Britain) and their responses to questions about their own major publications and the publications that influenced them. They were asked to respond to two questions:

> *Tell me about two of your publications in the field that you regard as significant.*
>
> *Tell me about up to three publications by others that have had a major influence on your research work in the field.*

In fifteen chapters he then discusses the interviewees' major publications and the publications they nominate as influencing their work.

Readers might consider that there are 5-10 additional researchers who could have been interviewed, but there is no doubt that Fensham's list represents the top-flight, most productive, researchers in current science education. Thus, given the status of the author and the researchers interviewed, the book is an excellent source for ascertaining the competencies, concerns, theoretical assumptions, achievements, and usefulness of science education research. And the data is very revealing of the impact of philosophy of science on the researchers.

Twelve years ago, in a review of science education research, Fensham observed that 'The most conspicuous psychological influence on curriculum thinking in science since 1980 has been the constructivist view of learning' (Fensham 1992, p. 801). This judgement does not change in *Defining an Identity* where he observes that: 'The maturity and the robustness of what has evolved in science education research, as a result of the combination of alternative conceptions work with constructivist views of learning are attested to by the efforts to which some other researchers have gone to oppose its relevance for science teaching and learning' (p.143).

Inadequate preparation of science education researchers

The interviews do reveal a significant problem with 'The evolution of science education as a field of research': namely researchers in the field are ill-prepared for conducting much of the research. Fensham remarks on many occasions that the pioneer researchers came into the field either from a research position in the sciences or from senior positions in school teaching. For both paths, training in psychology, sociology, history or philosophy was exceptional. He mentions Joseph Schwab, 'a biologist with philosophical background' as an exception (p.20). He could have mentioned F.W. Westaway in the UK and Walter Jung in Germany, but not many others could have been named as exceptions to the general rule.

This failure of preparation did not change for second generation or younger researchers. Indeed it has perhaps got worse, as proportionally fewer science education researchers have the experience of scientific research that the founders of the discipline had. The interviews reveal that the overwhelming educational pattern for current researchers is: first an undergraduate science degree, followed by school teaching, then a doctoral degree in science education. As Fensham remarks 'Most researchers in science education have been teachers in schools, usually secondary ones, before their academic appointments' (p.164). Most have no rigorous undergraduate training in psychology, sociology, history or philosophy. At best, as Fensham observes, 'As part of their preparation for the development tasks, these teachers had opportunities to read and reflect on materials for science teaching in schools and education systems that were different from their own limited experience of science teaching' (p.22).

Science education research is dominated by psychological, largely learning theory, concerns. Even here preparation of researchers is weak. Fensham writes that 'science educators borrow psychological theories of learning … for example Bruner, Gagne and Piaget' (p.105). And he goes on to say, damningly, that 'The influence of these borrowings is better described as the lifting of slogan-like ideas from these theories' (p.105). Others have also drawn attention to the amateurish preparation for research that most in the field experience: Jay Lemke wrote 'Science education researchers are not often enough formally trained in the disciplines from which sociocultural perspectives and research methods derive. Most of us are self-taught or have learned these matters second-hand from others who are also not fully trained' (Lemke 2001, p.303). This is tantamount to saying that in science education research, normally the blind lead the blind.

Uncritical adoption of idealist and relativist positions

One effect of poor preparation is the extent to which shallow philosophy is so evident in the field. Fensham notes that 'About one fifth of the respondents listed a publication of influence from the history and philosophy of science' (p.56), and he goes on to comment that 'However, only two of these respondents were researchers who began after the 1980s' (p.56). The philosophers of influence among the first generation researchers were James Conant, Joseph Schwab and Thomas Kuhn.

Thomas Kuhn

Second generation researchers also mention Thomas Kuhn, with one saying 'Thomas Kuhn's *Structure of Scientific Revolutions* is one of the few books I've reread several times … It was extremely helpful in my thinking with all sorts of implications for teacher education and everything I did' (p.56).

Unfortunately the science education community took up Kuhn's ideas in an altogether uncritical way - in the words of two researchers, 'the community became a cheer-squad for Kuhn' (Loving and Cobern 2000). Kuhn is more cited than read; the mere citation of Kuhn is considered to constitute an argument or to provide evidence for some philosophical view. One paper of an interviewee begins with the ringing claim that: 'In recent years, the rational foundations of Western science and the self-perpetuating belief in the scientific method have come into question …. The notion of finding a truth for reality is highly questionable' (Fleer 1999, p.119). Characteristically, no evidence is adduced for this sweeping claim except to cite, without pagination, Kuhn (and Bleier).

It is intellectually irresponsible to simply cite Kuhn and think that that is enough to establish a philosophical point. There have been extensive philosophical critiques of Kuhn's notions of paradigm, incommensurability, theory dependence of observation, intra-theoretic rationality, and so on (Hoyningen-Huene and Sankey 2001, Horwich 1993). One recent sympathetic appraisal of Kuhn correctly maintains that: 'Kuhn's treatment of philosophical ideas is neither systematic nor rigorous. He rarely engaged in the stock-in-trade of modern philosophers, the careful and precise analysis of the details of other philosopher's views, and when he did so the results were not encouraging' (Bird 2000, p. IX). In an older, 'first generation' appraisal, Abner Shimony, a physicist and philosopher, said of the key Kuhnian move of deriving methodological lessons from scientific practice that: 'His work deserves censure on this point whatever the answer might turn out to be, just because it treats central problems of methodology elliptically, ambiguously, and without the attention to details that is essential for controlled analysis' (Shimony 1976, p.582). Stephen Toulmin also urged caution on this very point, saying: 'Indeed, the more keenly one is aware of the interdependence of concepts and their contexts, the more indispensable certain distinctions become: for instance, that between the intrinsic authority of ideas and the magisterial authority of books, men and institutions' (Toulmin 1972, p.117). David Stove maintained that this confusion of sociology with epistemology is: 'the reason why Kuhn can, and must, sentence all present and future philosophers of science to the torments of the damned: that is, to reading the sociology of science' (Stove 1982, p.19).

This substitution of sociology for methodology of science is repeated in many current science education calls for 'authentic science' in classrooms. Authentic science is frequently understood to be just whatever scientists do in the laboratory. But scientists do lots of things in the laboratory – eat lunch, do crosswords, clean equipment, make phone calls, perform calculations etc. – it is the *epistemological* things that they do which ought to be of concern. And further it is the *good* or *proper* epistemological thinking and decision making which is of real concern, not the frequently bad or improper scientific practices. But these latter distinctions cannot be made just on the basis of sociology, they require a philosophical determination.

Kuhn admits that he is an interloper to philosophy, having never taken a course in the subject; and he candidly confesses that his treatment of philosophical issues in his famous *Structure of Scientific Revolutions* was ‘irresponsible’ (Conant and Haugeland 2000, p.305). He also admitted to a ‘good deal of embarrassment’ about the fact that he did not know of Rudolf Carnap’s work when he wrote *Structure* (Conant and Haugeland 2000, p.306).

This is more than just embarrassing: it is revealing of the origins of the whole Kuhnian Phenomena. From the moment the second edition of *Structure* was published in 1970, ‘Kuhnianism’ swept the academic world. But any academic writing about the topics covered in *Structure* should have known and engaged with Carnap’s work. Over a fifty-year period Carnap published hundreds of articles, wrote numerous books and edited many collections, including the volume of *The International Encyclopedia of Unified Science* in which *Structure* made its first appearance in 1962. Carnap had a life-time engagement with the interplay of philosophy and science, including concerns with theory dependence, confirmation, empirical adequacy, and theory appraisal (Schilpp 1963). And of course, Carnap was not the only philosopher ignored: there are remarkably few philosophers cited in *Structure* and almost no philosophical argument is elaborated or commented upon in the book. This set an unfortunate precedent for those rushing to endorse and follow Kuhn.

In reviewing his achievements, he regretted the ‘purple passages’ he wrote in *Structure*. Unfortunately it was often the purple passages that were seized on by so many in the science education community; by the time Kuhn regretted them they had taken root in countless research fields, including science education.

Kuhn himself recognised that sociology could not substitute for philosophy; that descriptions of what scientists may or may not be doing cannot substitute for methodological reflection. In a much remarked-upon lecture at Harvard University in 1991, he said: 'I am among those who have found the claims of the strong program absurd: an example of deconstruction gone mad. And the more qualified sociological and historical formulations that currently strive to replace it are, in my view, scarcely more satisfactory' (Kuhn 1991/2000, p.9).

Unfortunately the science education community paid little attention to either the first or second generation of Kuhn critics, and no attention to Kuhn's own belated 'clarifications' if not retractions of his ideas.

Ernst von Glasersfeld

The second most influential philosopher for Fensham's 'Top 80' researchers is Ernst von Glasersfeld. Fensham states that 'von Glasersfeld's many writings on personal constructivism have had a very widespread influence on researchers in science education …. In their published research he is regularly cited as a general source for constructivist learning'; he is a person who has had a 'most significant influence' on science education research (p.5). This is undoubtedly true, though a recent article has argued that his influence while deep is narrow; they claim that von Glasersfeld has had a big effect but on a few people (Gil-Pérez et al. 2002).

Ernst von Glasersfeld's radical constructivism embraces at least nine relativist epistemological and idealist ontological theses (Matthews 1994, 148-158). He provides a faithful summary of these theses when he asserts that: 'For constructivists, therefore, the word *knowledge* refers to a commodity that is radically different from the objective representation of an observer-independent world which the mainstream of the Western philosophical tradition has been looking for. Instead, *knowledge* refers to conceptual structures that epistemic agents, given the range of present experience within their tradition of thought and language, consider viable (Glasersfeld 1989, p.124). This is relativism of an individualist kind – knowledge is whatever belief is experientially viable to an individual cognizing subject or agent.

In other places he asserts idealist ontology. For instance he maintains that: 'for the constructivist there are no structures other than those which the knower constitutes by his very own activity of coordination of experiential particles' (Glasersfeld 1987, p.104). There are no structures, or mechanisms, in the world; structures and mechanisms are projected onto the world, they are subjective creations.

One interviewee, and enthusiast for von Glasersfeld's constructivism, has written that: 'according to radical constructivism, we live forever in our own, self-constructed worlds; the world cannot ever be described apart from our frames of experience. This understanding is consistent with the view that there are as many worlds as there are knowers' (Roth 1995, p.13). He goes on to state that 'Radical constructivism forces us to abandon the traditional distinction between knowledge and beliefs. This distinction only makes sense within an objective-realist view of the world …' (p.14). And for good measure he adds that: 'Through this research [sociology of science], we have come to realize that scientific rationality and special problem solving skills are parts of a myth' (p.31).

Another interviewee, who lists von Glasersfeld among his significant influences, writes that: 'constructivists chose to consider knowledge as an internally coherent system that we actively build up from within for our own purposes, coping with the world of our individual experience' (Staver 1998, p.505). Another interviewee makes a concession to realism, but still asserts that: 'Although we may assume the existence of an external world we do not have direct access to it; science as public knowledge is not so much a discovery as a carefully checked construction' (Driver and Oldham 1986, p.109). What the construction is checked against we are not told.

Science education researchers may not have been so influenced by von Glasersfeld's constructivist restatement of Bishop Berkeley if they had done an undergraduate philosophy programme where Berkeley's theory of perception, his account of mental imagery and ideas, his theory of knowledge and his critiques of Newtonian science are all routinely criticized.

This philosophical idealism is very heady stuff, and it has intoxicated a good many science educators, but is it correct? As with Thomas Kuhn, von Glasersfeld acknowledges that he has no training in philosophy, and describes himself as an amateur in the field (Glasersfeld 1995, p.4). This shows. His philosophical position is largely Bishop Berkeley's empiricism, with some Piagetian additives.

Wallis Suchting exposed a host of philosophical problems with von Glasersfeld's position, and in a lengthy critique concluded that: 'First, much of the doctrine known as 'constructivism' ... is simply unintelligible. Second, to the extent that it is intelligible ... it is simply confused. Third, there is a complete absence of any argument for whatever positions can be made out. ... In general, far from being what it is claimed to be, namely, the New Age in philosophy of science, an even slightly perceptive ear can detect the familiar voice of a really quite primitive, traditional subjectivistic empiricism with some overtones of diverse provenance like Piaget and Kuhn' (Suchting 1992, p. 247). Other scholars have made the same judgement on von Glasersfeld's subjectivism and his idealism (Nola 1997, Siegel 2004). But their arguments have been largely ignored in the science education community. Suchting's name does not even appear in the Name Index of von Glasersfeld's 1995 book *Radical Constructivism*.

Fensham recognises the general shallowness of philosophical thought in the field, and says that 'It will be ironic if, at the time when more attention is being given to the nature of science in the school curriculum, the researchers in the area have less commitment to this aspect than their predecessors had' (p.56).

The Edinburgh Strong Programme and science education research

Another indicator of inadequate foundational training is the extent to which the claims of the 'Strong Programme in the Sociology of Scientific Knowledge' (SSK) are uncritically endorsed by interviewees. Fensham reports that: 'One book stood out as an influence about the culture of science and that was Latour and Woolgar's *Laboratory Life'* (1979, p.58). One interviewee said the book 'legitimised the notion that you could study science from an anthropological perspective' (p.77). Another interviewee has stated that contemporary social studies of science reveal science to be: 'mechanistic, materialist, reductionist, empirical, rational, decontextualized, mathematically idealized, communal, ideological, masculine, elitist, competitive, exploitive, impersonal, and violent' (Aikenhead 1997, p. 220). Clearly a lot hinges on the correctness or otherwise of this analysis. If Aikenhead's picture is a correct account of the scientific enterprise, then teaching science is truly a problematic activity.

That *Laboratory Life* has had the impact it has had is indicative of the short-comings of the field. The book is at the extreme, idealist, wing of the SSK movement. It is an attempt at an anthropological study of laboratory research on THR (thyrotropin releasing hormone) where one author, Latour, thought it advantageous that he knew absolutely no science. The book argues that all science is 'the construction of fictions', and that scientific success is simply the ability of one group, in this case the Nobel Prize winners Schally and Guillemin, to 'extract compliance' from another.

The authors of *Laboratory Life* make the idealist claim that THR exists only if a certain bioassay procedure is accepted. However this claim rests on a philosophical confusion: The bioassay result might be grounds for *believing* in THR, but hardly grounds for THR existing. More generally they blithely state the idealist claim that the 'out-there-ness [i.e. the external world] is the consequence of scientific work rather than its cause' (Latour and Woolgar 1986, p.82). Other adherents of the SSK programme make the same idealist claim about celestial bodies, which supposedly only come into existence when discovered; they are 'cultural objects' that can come in and out of existence as culture or politics demands (Garfinkel, Lynch and Livingston 1981). And so on for all discoveries, or 'discoveries' as SSK devotees with a fondness for scare quotes would prefer.

Ernst von Glasersfeld made the same point, saying at one stage that 'Intelligence organizes the world by organizing itself'. This is idealism in its purest form: it is the claim that the world is dependent upon our mind, and changes as our mind changes. A realist takes the opposite lesson from the history of science: the world is organized well before our mind makes contact with it; and the slow business of scientific growth is an attempt to grasp its organization and fundamental mechanisms. The earth was rotating around the sun long before Copernicus advanced the idea; evolution was occurring by natural selection well before Darwin made the conjecture; and the continents were drifting apart long before Wegener defended the supposition.

For Latour and Woolgar, 'science is a form of fiction or discourse like any other, one effect of which is the "truth effect", which (like all literary effects) arises from textual characteristics' (Latour and Woolgar 1986, p.184). Thus they can assert that 'there is little to be gained by maintaining the distinction between the "politics" of science and its "truth" (p.237).

This is a truly remarkable statement, and one can only wonder how it could be so calmly stated. The view was anticipated, one might say, by the State Legislature of Indiana in 1897 which passed unanimously a bill to legislate the value of π. Although the politicians had the legal power, they got the science wrong (Beckmann 1971, p.174). More notoriously the distinction between politics and truth was blurred if not rejected in the sixteenth and seventeenth centuries by the Inquisition, and in the twentieth century by Hitler's Aryan Science, Stalin's Marxist Science, various state-sponsored Islamic Science enterprises, and church-sponsored Creation Science. Hans Schemm's, Bavaria's Nazi Minister for Instruction and Culture, put the position quite bluntly when he said to scientists and teachers, that: 'From now on, the question for you is not to determine whether something is true, but to determine whether it is in the spirit of National Socialist Revolution' (Beyerchen 1977, p.52). Surely the lesson to be drawn from these cases is precisely the opposite of that advocated by Latour and Woolgar – advance in science, to say nothing of the promotion of human welfare, requires that the distinction between politics and truth to be constantly reaffirmed.

However the 'truth-effect' in science, if one can bear to speak this way, does not arise from textual characteristics but from the characteristics of experiments and observations. Scientists, and children in classrooms, are encouraged to hypothesize about some effect, then conduct observations or experiments to check the veracity of their hypothesis. The answer may not be immediate, and there are usually refinements required, but hopefully they are not asked to look at their own text and report if they are feeling a 'truth effect'.

This very point was made four hundred years ago by Galileo, who in answering the Aristotelian Simplico's objection to the existence of sun spots, said:

> If what we are discussing were a point of law or of the humanities, in which neither true nor false exists, one might trust in subtlety of mind and readiness of tongue and in the greater experience of the writers, and expect him who excelled in those things to make his reasoning most plausible, and one might judge it to be the best. But in the natural sciences, whose conclusions are true and necessary and have nothing to do with human will, one must take care not to place oneself in the defense of error; for here a thousand Demostheneses and a thousand Aristotles would be left in the lurch by every mediocre wit who happened to hit upon the truth for himself (Galileo 1633/1953, pp 53).

Latour, Woolgar and those more deeply affected by them, believe that the efforts of Galileo, Newton, Darwin, Einstein, and the roll-call of contributors to the scientific tradition, have not revealed truths about the world, but have revealed how to succeed in science, and this success owes nothing to any fit between scientific claims and the world. The arguments of *Laboratory Life* have been soundly criticised by historians and philosophers of science (Slezak 2000). Even David Bloor, a founding member of the Edinburgh School, described Latour's procedure as 'obscurantism raised to the level of a general methodological principle' (Bloor 1999, p.97).

That *Laboratory Life* should be so often nominated as an 'important influence' by Fensham's 80 key international science educators is truly disturbing, and another example of what can go wrong with a research field when the basics are missing. A good grounding in the history and philosophy of science, which few of the interviewees have, would inoculate them against what David Stove generously called 'philosophical folly', and other philosophers have called far worse. What intellectual nourishment science educators can find in such an anti-scientific doctrine is difficult to imagine; worse to imagine is the effect on students who are given one-sided exposure to this material.

What is in a name: misconceptions or alternative conceptions?

The extent to which the heady mix of Kuhnian and Strong Programme relativism has gripped science education research is revealed when Fensham himself, discussing alternative conception research, says: 'The continued use by some researchers particularly in the USA of the term *misconceptions* for the findings of alternative conceptions research in science education encourages a response to them that merely looks for cognitive change pedagogies' (p.153). Fensham thinks it wrong for teachers and researchers to judge children's ideas as wrong, as misconceptions. He prefers the non-judgmental 'alternative conception' label, and objects to misconception-inspired teaching strategies that 'may lead, or embarrass learners into accepting the unquestioned science content as prescribed in the curriculum, or its companion, the textbook' (p.153). Another interviewee in the study, and prominent researcher, preferred the term 'plural conceptual schemes' (Driver et al. 1994).

Such labeling is not just a pedagogical strategy to get kids on side and engaged in an examination of their views: Fensham asserts an epistemological point. He is against the 'unquestioned' science content of the curriculum or textbook, saying that: 'When it is accepted that the science content itself can be problematic, the research approach to alternative conceptions can, however, take several other forms (p.154). It certainly can take other forms, and thus the truth of the antecedent needs to be carefully examined. To claim that the 'science content is problematic' is very significant and should have been elaborated. In the absence of such elaboration there are three possible meanings.

1. The choice of content for a science curriculum is problematic. This is assuredly so, but it is not controversial. Is curriculum content decided on student interest, on teacher interest, on state interest? Is the curriculum content based on the structure of the science disciplines or on broadly utilitarian grounds? These options for curriculum content have been laid out nicely by Roberts (1982) twenty years ago. This does not seem to be Fensham's point.

2. The content of science programmes is problematic in the sense that the claims of physics, chemistry, biology and so on are not absolutely true

and finalised. This is the view that science is fallible, it is not perfect truth, but it is the best we have. Again this is not controversial, few if any people, believe that science provides absolute truths, whatever they might be. Again, this does not seem to be the point Fensham wishes to make.

3. The content of science is problematic in the sense that there are equally good alternative sciences, or equally good other ways of knowing about the world. This might be called the 'multi-science' thesis.

It is this third claim that Fensham seems to endorse and it certainly does lead research in other directions apart from the previously well-trod, if difficult, path of trying to find out how kids might best learn mainstream science. The different directions flowing from an 'alternative conception' view of misconceptions have been taken, and are most evident in multicultural, feminist and most recently queer science education research.

Multiculturalism

The multi-science thesis is widespread among multicultural advocates in science education. It has been stated clearly by Sandra Harding, a feminist philosopher who has had great impact on science education. She asserts that:

> A central focus of recent work in the social and cultural studies of science and technology … has been to show how modern sciences have been constituted by their practices and cultures, not just externally enabled by them in ways that leave no mark on their cognitive cores. They are local knowledge systems or, in other words, 'ethno-sciences'. Most of these authors have insisted in

> abandoning claims to universality, objectivity and rationality for modern sciences. (Harding 1997, p.37)

One interviewee in Fensham's study, and a former editor of the *Journal of Research in Science Teaching* echoed these words when he wrote: 'We have reached a time in society where we can no longer afford to make comparisons between different kinds of knowledge in Western and non-Western cultures. It is simply not productive to raise questions about the status of knowledge. Rather, we must acknowledge that multiple knowledges exist …' (Kyle 1999, p.260). Another interviewee, with a colleague, writes about the current 'shift away from the Eurocentric hierarchical view of nature-knowledge systems' as a 'paradigm shift' in science education, and likens this shift to Galileo's revolution in Western science (Lewis and Aikenhead 2001, p.4). The same authors warn, that just like Galileo, 'science educators may have similar problems shedding concepts culturally ingrained by the ideologies and conceptualizations of their Western science' (p.5).

Despite widespread enthusiasm in science education for such apparently culturally sensitive positions, they have major philosophical and political problems that should be faced. Some of these have been pointed out by Meera Nanda who wrote: 'My reason for urging a rejection of ethnoscience is this: What from the perspective of Western liberal givers looks like a tolerant, non-judgemental, therapeutic "permission to be different" appears to some of us "others" as a condescending act of charity. … This kind of charity, moreover, enjoins us to stop struggling against the limits that our cultural heritage imposes on our knowledge and our freedoms and to accept – and in some Third Worldist and feminist accounts, even celebrate – these cultural bonds as the ultimate source of all "authentic" norms of truth' (Nanda 1998, p.288).

Other fundamental problems have been pointed out by, among others, Harvey Siegel (Siegel 1997) and by myself in an earlier work (Matthews 1994, chap.9).

Feminism

The multi-science thesis is widespread among feminist science educators. It has been stated by a prominent researcher (not interviewed) who wrote: '…feminist epistemologies [have had] a significant impact on science education. The work of feminists such as Evelyn Fox Keller, Donna Haraway, and Sandra Harding showed the ways in which scientific knowledge, like other forms of knowledge, is culturally situated and therefore reflects the gender and racial ideologies of societies. … Science cannot produce culture-free, gender-neutral knowledge because Enlightenment epistemology of science is imbued with cultural meanings of gender' (Brickhouse 2001, p.284).

Feminist epistemology certainly has had a significant impact on science education, and there is widespread enthusiasm for it, but notwithstanding the enthusiasm, it has its own philosophical and political problems. Among many feminists who have pointed to philosophical problems with feminist epistemology is Cassandra Pinnick who, commenting on Harding's work, writes: 'if Harding chooses to use the philosophical arguments that she believes license a standpoint theory of knowledge – arguments relying on Kuhn and Quine and theorizing associated with the Strong Programme – then she must own up to the logical consequences of such views. Thus, it becomes inconsistent for her to say that every epistemology is a tool of the power elite while maintaining that a particular epistemology, feminist epistemology, generates "less distorted" methods and beliefs. The first claim forecloses the possibility of justifying the latter type of claim on behalf of any particular epistemology' (Pinnick 2003, p.29). In response to Harding's acknowledgement of the 'contradictory nature' of feminist epistemology when accommodating 'multiple perspectives' [race, gender, class, culture], Pinnick writes: 'A philosophy of science qua social science whose only goal is to tell inconsistent and incoherent stories is neither appealing nor sufficiently ambitious' (Pinnick 2003, p.30).

Some of the political problems of feminist epistemology have been pointed out by Susan Haack who wrote: 'But the key step comes with the claim that the discovery of sexism in scientific theorizing obliges us to acknowledge political considerations as legitimate ways to decide between theories. On the face of it, however, criticisms of sexism in scientific theorizing suggest exactly the opposite conclusion: that the ideal is for acceptance to be appropriately correlated with warrant, with quality of evidence – and that politics should be kept out of science' (Haack 2003, p.11).

Queerism

The multi-science thesis has recently been championed by advocates of queer science.[2] Two such researchers have, this year, in the *Journal of*

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[2] Editors' Note: "Queer theory", invented in the 1990's questions the distinction between biology and culture. While it critiques the normative and the deviant in all fields, it focuses on these with reference to sexual activities and identities.

Research in Science Teaching claimed that: 'Using the lens of queer theory, we can view the hegemonic matrix, interrupt heteronormative thinking, and broaden all students' potential for interpreting, representing, and perceiving experiences. In other words, queering excavates and frees the same skills students need for inquiry and learning in the biology classroom' (Snyder and Broadway 2004, p.621). Queer theory, apparently, 'is both ontological and epistemological as it questions knowing and the nature of being' (Snyder and Broadway 2004, p.619).

The authors further claim that: 'Language limits our ability to see truths of nature thus the search for truths should be abandoned for the search of understanding the descriptors that shape our lives' (Snyder and Broadway 2004, p.620). On the face of it, this last claim means abandoning science and solely pursuing hermeneutical studies. Indeed, the authors do endorse just such a position when later they write: 'Truth of nature, then, becomes cultural interpretations of meaning' (p.623).

This truly revolutionary position is at least consistent with the premises of queerism but it is simply inconsistent with the pursuit of orthodox science education: hermeneutics is a necessary part of science education, students assuredly must understand the meanings of technical words and theoretical concepts, but science education also depends on words having *reference* in nature not just meaning. The whole enterprise of developing better technology to explore the micro-world and the astronomical-world is predicated upon the assumption that there is a possible reference for scientific terms (microbe, bacteria, asteroid, embolism, planet, black holes, ion, etc.) and that careful observation and experimentation is germane to determining whether there is such a referent and what its properties are. It is a hermeneutical task to ascertain the *meaning* of 'Santa Claus', it is a s*cientific task* to see if the term has reference. The above authors do not seem to appreciate the difference.

The authors' basic point was also made four hundred years ago, this time by Francis Bacon in his discussion of Idols of the Mind when he warned that: 'And therefore the ill and unfit choice of words wonderfully obstructs the understanding … and lead men away into numberless empty controversies and idle fancies' (Bacon 1620). However the lesson drawn by Bacon was the need to be careful and diligent about the use of words. Not to despair of them and say that words inherently 'limit our ability to see truths of nature'. This position is hopeless for two reasons: first, it encourages people to be sloppy and ill-considered in their use of words, after all if words are an epistemological menace, why be careful with them? Second, it invites the question: If not words, then what? Words are all that we have, if they inherently obfuscate, then not only science has to be abandoned, but the bulk of human communication also has to be abandoned. If a visitor is asked 'Are you hungry?' we take the answer 'yes' to indicate that they are indeed hungry. On the revolutionary position enunciated by Snyder and Broadway, the simple answer conceals, not reveals, the true state of our visitor's gastronomic desires. And how queer theorists are supposed to 'question the nature of knowing and being' without using language to articulate their questions we are not told.

In the above three cases, research certainly does take, as Fensham says, 'different approaches' if science content is sufficiently problematised, but if the philosophical foundation for all three is mistaken, then the research programme generated will be misguided and a massive waste of everyone's time and energy. The programmes are only as good as their intellectual foundations; but most adherents in science education do not give them the scrutiny they warrant. Again, it is mostly a case of picking up slogans, or ‘purple passages’ and running with them.

Does science education research make progress?

In chapter nine Fensham addresses the all-important question of ‘evidence of progress’ in the field. Early in the book Fensham gives one account of how progress might be judged when he quotes the opinion of John Mason that: ‘the most significant products of research in mathematical education are the transformations in the being of the researcher’ (p.37), and embraces the centrality of personal transformation for science education research.

The conviction that the most significant product of science education research is the ‘transformation in the being of the researchers’ is arresting, to say the least. Many, including research funding agencies, might reasonably expect the most significant products of such research to be a better knowledge of how children learn science, or how teachers can best teach science, or what curriculum is most appropriate for different groups. Many would say that transformation in the being of researchers is reasonably thought of as a by-product of research, not the purpose of the research; and it is a mistake to confuse autobiography with research. Both are valuable, but they are different things. The cost of conflation is narcissism; and distraction from the core purpose of research, namely finding out about the natural and social world. This valuing of ‘personal transformation’ by research perhaps accounts for the highly personal tone of the book, where in the Introduction of seven pages, the personal pronoun occurs 50 times.

Fensham does look to other things besides personal transformation when he discusses whether or not progress has been made in science education research. He cautions the reader that 'movement should not, however, be confused with progress' (p.134), and he uses the Illysian image of a 'butterfly moving from flower to flower' to warn that such movement is just 'replication', not progress. He rightly points out that the fact of lots of publications in a field does not necessarily mean there has been progress, especially in a field where, as he earlier points out, multiple publishing has flourished. He comments that 'The same piece of research …. can be found in several quality journals' (p.75), and 'I find myself as a referee, for a wide range of journals, …. to be pointing out to an editor that this study has already been published elsewhere' (p.75).

As well as multiple publication, Fensham also points to another factor bulking up science education research. He observes that: '*past-the-used-by-date* publishing is much more common in science education ...' (p.144); and cautions that 'This new domain for science education research has turned out, for some researchers, to be a place to mark step, producing studies of the conceptions of a number of different science phenomena, or producing replications of the same phenomena with another group of students' (p.138).

But if mere movement is not progress, then what constitutes progress in a research field? Unfortunately Fensham skirts around this central question.

It is clear that there can be thriving research fields that meet all of Fensham's fourteen criteria, but nevertheless tell us nothing about the world; they are mistaken research fields. There may well be communities of researchers, conferences, journals, research methods, and implications for practice – some of Fensham's identifying criteria – but simply no knowledge created. Such failed programmes are scattered over the natural and social science landscape. Think of Lyenskoist genetics in the Soviet Union which despite meeting all of Fensham's criteria, simply produced no knowledge of the world (and consequently produced disastrous recommendations for agricultural practice).

Likewise think of the research community of phrenologists in Europe, UK, and the US in the early to late nineteenth century. They undoubtedly constituted a research field - they had meetings, had journals, and made numerous recommendations about medical, legal and social practice - but they did not contribute knowledge about the world, and consequently made disastrous policy recommendations.

More recently think of the impact of behaviourism in learning theory. This constituted a huge research field, with numerous national and international conferences being held over a period of decades, scores of scholarly journals being published, an NSSE Yearbook was devoted to the subject (1978), tens of thousands of BA's and BSc's, and thousands of PhD's, were graduated, an enormous array of implications for classroom management, teaching and psychotherapy were promulgated, and so on. Was knowledge produced? The answer requires a long story, but in brief it is 'not much'. The academic mountain shook and produced a pedagogical mouse (or perhaps one might say a rat). The basic problems were conceptual and philosophical: behaviourists had a faulty definition of human learning.

In the above cases, and more can be added – think of current astrological research, there is lots of research activity or 'movement' and undoubtedly 'the being' of countless researchers was and is transformed, but one can reasonably ask was any knowledge produced? The answer is no. Is the vast quantity of research in science education any different from the mass of Lysenkoist, phrenological, and behaviourist research now completely ignored and left to gather dust on library shelves?

Fensham does not pursue this question, and his constructivist leanings make it difficult to ask. For most constructivists, certainly ones influenced by von Glasersfeld's epistemology, knowledge is whatever beliefs are viable in a person's experiential world. The problem is that many, if not most, mistaken views are completely viable to those who hold them. Thus, for constructivists, if 'progress' in a research field is linked to knowledge acquisition, then progress is indeterminate, new theories are progressive for some, and not progressive for others.

The most explicit statement Fensham makes about what constitutes progress is when he says research is progressive if it 'has been progressive in the sense of understanding science classrooms' (p.133). But this is both too narrow and too wide: too narrow, because there are lots of other specific things reasonably expected of science education research other than understanding classrooms; it is too wide, because just about anything can claim to be an 'understanding of science classrooms'. What does this possibly mean? What would constitute not understanding a science classroom? At another point he recognises that constructivism has for 25 years dominated science education research, and he proffers that 'assessing what has been achieved [by constructivism].... has been taken up by several authors' (p.135). He implies that the assessments indicate progress, but he does not elaborate.

It is a pity that this point was not pursued as appraising constructivism is a fitting test of whether science education research has produced knowledge and useful recommendations for the conduct and organisation of science teaching, or whether it has produced just mere publications - 'movement' - and 'personal transformation'. Contrary to Fensham, a number of researchers believe that constructivism has produced philosophical confusion and has misdirected educational effort (Nola 1997, Siegel 2004, Slezak 2000, Small 2003, Matthews 1993, 2000). An examination of these rival claims would cast significant light on the overall question that Fensham is pursuing in the book.

Conclusion

Based on Fensham's interviews with the 'Who's Who' of science education research one can reasonably conclude that a good many of the research programmes in science education have suffered because researchers have either embraced or been badly influenced by mistaken philosophy. Further it is clear that researchers are not adequately prepared in the foundation disciplines that underwrite their research programmes – specifically learning theory (including cognitive science), and philosophy (especially the history and philosophy of science). Fensham acknowledges that researchers are ill-prepared, that they 'borrow' from the foundation disciplines, and that a major problem is that 'Theoretical positions were being presented and used in a form that suited the authors' studies, although this theoretical position had been revised as a result of studies and work these authors had not read or wished to ignore' (p.144). So the work of Kuhn, von Glasersfeld, Latour, Bruner, Lave, Harding, Giroux and others is appropriated but the critiques of their work go unread; it is rare that science education researchers keep up with psychological and philosophical literature. This situation means that the field is susceptible to intellectual and ideological fads that retard the primary business of assisting science teaching and learning, as well as the secondary business of the personal growth of the researchers.

Fensham draws attention to the ‘considerable pressure to build a list of published work’ (p.75) that affects the entire profession from top to bottom; it is the ‘publish or perish’ syndrome. This is an overriding reason why it is almost impossible for science educators to make up the shortfall in foundation training while on the job. The hot-house pressure induced by review and tenure committees means that very little time can be spent in the library, engaging in scholarship, or even in thinking. The demands to publish, to attend conferences, to engage in teacher development activities, to write grant proposals, and to develop new courses, are so great that finding time to carefully read a book such as Kuhn’s *Scientific Revolutions*, much less to read the source material that it is built on (the texts of the Galilean revolution, for instance), or the critical literature that flowed from it - is nigh well impossible. Conference presentations, in-service courses, publications - can all appear on a CV or in an annual report. Books carefully read, or courses attended, do not appear on CV’s and reports.

Some things that might mitigate the unfortunate situation are:

1. Instead of science teachers doing higher degrees in education (with a view to university appointment), encourage them first to do an undergraduate degree in an appropriate foundation discipline; after that do a PhD in Education. This is good for their personal growth or education, and it is ultimately beneficial to whatever research programme they might engage in.

2. Ensure that PhD committees in science education have foundations faculty on them. The participation of a psychology, philosophy or history researcher on thesis committees would contribute to raising candidate and supervisor awareness of past and current literature in the relevant disciplines.

3. Try as much as possible to ease publication pressure so that scholarship can be engaged in. This might amount to getting institutions to trade off quantity for quality in appraising a new staff member's output. Institutions should recognise that one substantial, long shelf-life publication contributes more to the field than ten or twenty or thirty second-rate, shallow, ill thought-out publications. The latter merely muddy the academic waters. Far better for science educators to spend a semester attending a philosophy, psychology or history course, and reading substantial books, than running around conducting yet another study of misconceptions or the impact of talking on class learning.

4. Encourage a system of joint appointments between education and foundation disciplines. Encouragingly this happens to a small extent between education and science disciplines, if other faculty could be cross-appointed to philosophy or HPS or psychology, this would assuredly lift the quality of scholarship and research in the field.

Realistically however, the sad situation the field finds itself in is not going to change any time soon.

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Discussion on the presentation

Query: In relation to shallow theorizing, take any mundane action (say tapping the mike) and give a description of this simple action in terms of any scientific theory, say, relativity, quantum theory, nuclear physics, etc.

Speaker: My ideas do not depend on providing such a description. There are multiple ways of describing the action, in scientific terms, such as acoustics, electronics etc.

Query: Do you want to do away with that is eliminate students' alternative scientific conceptions and suggest that teachers teach only what is "objective" science?

Speaker: Certainly we should do away with student's alternative conceptions. Most alternative natural conceptions are simply wrong. We know this and we want to do away with them. It is our business to do away with them. We as science educators need to help people come to realize that what they say as the sun "comes up and goes around the earth" is not what is happening, it's the earth, which comes out and goes around the sun. That explanation takes a lot to achieve.

Query: The challenge of articulating examples of the demarcation problem and of distinguishing or deciding what is science and what is not, is not resolved. Most philosophers of science have given many interesting suggestions but nothing has been provided in a convincing way such that science educators could start repeating all such observations. Secondly, the discourses of history and philosophy of science have not been able to prove that science is trans-natural. These ideas need to be addressed.

Speaker: I do not believe that there exist these two failures. In brief we can demark science from non-science. We can provide reasonable arguments for the universality of knowledge claims. It depends on what you regard as a knowledge claim and the answer would have the question built in. If knowledge is seen as an account of what is external to the subject, an account which is more or less true, if that is the account of knowledge, it is by definition universal.

Query: The definition of foundational fields of science education did not include science. Where would you place neurobiology (molecular level of learning)?

Speaker: I have included learning theory as the foundation of science education and it includes behavioural as well as neurobiological aspects. Nowadays the accounts of learning are becoming more biology, as someone put it, “Psychology without neurobiology is brainless”.

Appendix A
About the review speakers

Probal Dasgupta
University of Hyderabad, India

Dean of the School of Humanities and Professor of Linguistics at Hyderabad University, Probal Dasgupta has made major contributions to general, South Asian/ Indian, and Esperanto linguistics. His research ranges over a vast variety of topics, including current syntactic theory and comparative syntax, generative phonology and morphology, lexicology, Indo-Aryan linguistics (with focus on Bangla [Bengali]), sociolinguistics (including diglossia and South Asian English), psycholinguistics, and linguistic interfaces with literature and philosophy.

Dasgupta received his PhD in linguistics from New York University (NYU) in 1980 and has taught on linguistics faculties at NYU, University of Melbourne, University of Calcutta, Deccan College Post-Graduate and Research Institute (Pune, India), and since 1989, at University of Hyderabad, where he is at present. He has served as editor of *Indian Linguistics*, the journal of the Linguistic Society of India (1982-1987), as co-editor of *Language Problems and Language Planning* (John Benjamins, 1990-present), and associate editor of the *Yearbook of South Asian Languages and Linguistics* (Sage Publications, now with Mouton de Gruyter, 1998-present). He has provided valuable services to the Indian linguistic community by extension lectures on historical linguistics, the theory of government and binding, and morphology and phonotactics.

G. Nagarjuna
Homi Bhabha Centre for Science Education, India

Nagarjuna is an epistemologist with a Masters in biology and another in philosophy. He works in knowledge organization, history and philosophy of science, biological roots of cognition and science education. He obtained his doctorate in 1995 in the area of Philosophy of Science for his thesis on “The Role of Inversion in the Genesis, Development and the Structure of Scientific Knowledge” from Indian Institute of Technology, Kanpur. Since then he has been at the Homi Bhabha Centre for Science Education, a national centre of the Tata Institute of Fundamental Research, at Mumbai, India, where he engages in research and development on the implications of history and philosophy of science for education, cognitive development, and knowledge organization. The social, economic and political aspects of information technology also engage his serious attention. Dr. Nagarjuna is the Chairman of Free Software Foundation of India. He has authored a knowledge representation system called GNOWSYS (Gnowledge Networking and Organizing System) http://www.gnu.org/software/gnowsys/

Michael Matthews
University of New South Wales, Australia

Michael R. Matthews is an associate Professor in the School of Education at the University of New South Wales. He is also Foundation Editor of the journal Science & Education (Kluwer Academic Publishers). He has degrees from the University of Sydney in science, philosophy, psychology, history and philosophy of science, and education. His PhD is in philosophy of education from the University of New South Wales. Prof. Matthews has taught science in high school, and lectured in Education at Sydney Teachers' College and the University of New South Wales. He was the Foundation Professor of Science Education at the University of Auckland (1992-93). He has published in philosophy of education, history and philosophy of science, and science education.

His recent books include *Challenging New Zealand Science Education* (Dunmore Press, 1995), *Science Teaching: The Role of History and Philosophy of Science* (Routledge, 1994) and *Time for Science Education* (Plenum Publishers, 2000). Additionally he has edited *The Scientific Background to Modern Philosophy* (Hackett Publishing Company, 1989), *History, Philosophy and Science Teaching: Selected Readings* (OISE Press/ Teachers College Press, 1991), *Constructivism in Science Education: A Philosophical Examination* (Kluwer Academic Publishers, 1998), and *Science Education and Culture: The Role of History and Philosophy of Science* (with F. Bevilacqua & E. Giannetto, Kluwer Academic Publishers, 2001).

John F. Sowa
ex-IBM, USA

John F. Sowa spent thirty years working on research and development projects at IBM and another seven years teaching, writing, and consulting. He has a Bachelor's degree in mathematics from MIT, a Master's in applied mathematics from Harvard, and a doctorate in computer science from the Vrije Universiteit Brussel. He is a fellow of the American Association for Artificial Intelligence, and he has participated in standards projects for conceptual schemas, knowledge sharing, and ontology. In conjunction with these projects, he edited the draft of the proposed ANSI standard for conceptual graphs, which is based on the notation used in his books (Sowa 1984, 2000).

Kaye Stacey
The University of Melbourne, Australia

Kaye Stacey is an internationally renowned researcher, teacher, educator and author. Her books include *Thinking Mathematically, Strategies for Problem Solving,* and *Graphic Algebra,* and she has written over one hundred and fifty research papers and practically oriented articles for mathematics teachers. She was Head of the Department of Science and Mathematics Education from 1992 until 2000. Professor Stacey's research interests centre around students' mathematical thinking and problem solving, mathematics curriculum issues, and the impact of new technology on curriculum, assessment and teaching. She has graduate students working under her guidance in all of these areas. Stacey has a keen interest in teacher education, and teaches in the undergraduate pre-service course for primary teachers. Her research has been funded mainly by the Australian Research Council.

David Treagust
Curtin University of Technology, Australia

Professor David Treagust is the Deputy Dean of the Faculty of Graduate Studies within the Division of Engineering, Science and Computing at Curtin University of Technology. He holds a PhD from the University of Iowa, USA. His research and thesis span several topics: Identification, design and implementation of intervention strategies to challenge students' conceptions; how intervention strategies can contribute to an enhanced understanding of science concepts, the long-term consequences on conceptual change and the development of scientific knowledge; Design of tests and other assessment instruments to diagnose student understanding of content in specific science areas; development of diagnostic instruments in specific content areas to assess understanding of concepts as opposed to the possession of information; students' use of analogies and models as an aid to their understanding of science concepts; teachers' use of representations such as analogies and models to enhance understanding of science concepts; and how students use different representations to help understanding of science concepts.

Marc J. De Vries
Eindhoven University of Technology, the Netherlands

Marc J. De Vries is an assistant Professor of philosophy and methodology of technology, Eindhoven University of Technology, the Netherlands. Previously, he was a teacher educator at a teacher training college for technology education and vocational technical education in Eindhoven. Dr. de Vries has published and presented internationally on technology education, student assessment, and the philosophy of technology. A 100-question survey instrument he developed, the Pupils' Attitudes Toward Technology (PATT), has been used in some 30 countries to gauge student understanding of technological ideas.

Since 1999, de Vries has been the editor-in-chief of the International Journal for Technology Education and Design and has been a co-organizer of 12 international PATT conferences. He has served as an advisor on technology education development and assessment for UNESCO and OECD. He has worked with Dutch educational television to produce broadcasts on technology and co-authored a number of textbooks for grades 7-9. He was co-founder of the Dutch technology teacher association. At Eindhoven University, he chaired a quality assessment committee for the STS programme in which he teaches. His current research is focused on the nature of technological knowledge.

Appendix B

List of paper presenters

1. S. C. Agarkar: *Cross-cultural research in learning hurdles in science and mathematics*

2. Anjana Arora: *Levels of inquiry: role of language and assessment*

3. Senthil Babu: *Tamil mathematical manuscripts and the possibility of a social history of Math education*

4. John Backwell: *The design and development of cognitive acceleration through technology education: implications for teacher education*

5. Rakhi Banerjee: *Term as a bridge concept between arithmetic and algebra*

6. Abhijeet Bardapurkar*: Students' explanations: a review of how students understand the theory of evolution*

7. Sugra Chunawala: *Placing technology education within the gender perspective*

8. Bronislaw Czarnocha: *Teaching-research and the design experiment - two methodologies of integrating research and classroom practice*

9. Patrick Dias: *Culture, language and cognition*

10. Satyendra Giri: *High achievement in mathematics and the girl child*

11. Nelofer Halai*: Understanding science teaching and conceptions of the nature of science in Pakistan*

12. V. G. Jadhao: *The concept of force*
13. Barbara Jaworski: *Inquiry as a tool and as a way of being in mathematics teaching development*
14. Yung Sik Kim: *Problems and possibilities of general science education for college students*
15. Bodil Kleve: *Teachers' implementation of a curriculum reform*
16. Ravinder Koul : *Epistemological stances towards knowledge in school science and the cultural context of India*
17. Verdiana Masanja: *Gender disparity in science and mathematics education*
18. Usha Menon: *The teaching of place value – cognitive considerations*
19. Zemira Mevarech: *The effects of meta-cognitive instruction embedded within asynchronous learning network on scientific inquiry skills*
20. Punyashloke Mishra: *Visions and mandates: an analysis of Indian IT curriculum frameworks*
21. C. K. Raju: *Math wars and the epistemic divide*
22. Mridula Ranade: *Science teaching through computer assisted instruction the design of a case-based multimedia environment for pre-service teachers*
23. Sadhna Saxena: *Teacher as constructor of knowledge: an analysis of teachers' contribution to the HSTP*

24. T. V. Venkateswaran: *Words and world-views: scientific technical terms in Tamil*

25. Purvi Vora: *Project YUVA*

26. Orit Zaslavsky: *Transparent objects and processes in learning mathematics*

Appendix C

List of poster presenters

1. Francis A. Adesoji and Oludipe Oladele: *Student and teacher related variables as determinants of secondary school students' academic achievement in chemistry*
2. Margarida Afonso: *Teachers' and students' ideas about sociology of science: A study at the level of primary school*
3. Kulwanti Bellara, Suma Nair and Baktaver Mahajan: *Action-based science education for health and environment*
4. P. K. Bhattacharyya*: To identify and structure technology that has already crept into the school curriculum*
5. Nicole Carignan, Roland G. Pourdawood and Lonnie C. King: *For a "village" involvement: social representations on pluricultural school community actors*
6. Ansuman Chattopadhyay and Bakhtaver S. Mahajan: *Students' understanding of DNA and DNA technologies after "Fifty years of DNA Double Helix"*
7. Pradeep M. Dass: *Professional development of K-12 science teachers: History of reform and effects of a Science-Technology-Society (STS) approach in bringing about the reform*
8. Carmel M. Diezmann: *Diagrammatic knowledge in mathematics in the information age*
9. Jaya Earnest: *Health education in Timor Leste (East Timor): A case study*

10. Jazlin Ebenezer, Sheela Chacko and Nanibala Immanuel: C*ommon knowledge construction model for teaching and learning science: applications in the Indian context*

11. Pranita Gopal: Concept Mapping - *A pedagogical tool for grammar lessons*

12. Lilia Halim, Kamisah Osman and T. Subahan M. Meerah: *Trends and issues of research on in-service needs assessment of science teachers: global vs the Malaysian context*

13. James Kakooza: *Mathematics and gender in Ugandan primary school: influence on teachers, parents and learners*

14. Meena Kharatmal and Nagarjuna G.: *Knowledge organisers of cell biology*

15. Ritesh Khunyakari, Swati Mehrotra, Sugra Chunawala and Chitra Natarajan: *Design as drawings: Analyzing drawings of middle school students in technology education tasks*

16. Bracha Kramarski and Nura Resh: *Investigating teachers' pedagogical beliefs about mathematics, science and reading literacy in the PISA project*

17. David Devraj Kumar: *A study of laptops in science education*

18. Chel Madan Mohan: *A study on integration of teaching science and mathematics*

19. Barbara M. Moskal: Outreach in Engineering Education: *the GK-12 learning partnership program.*

20. Sindhu Mathai and Jayashree Ramadas: *Putting imagery back into learning: The case of drawings in human physiology*

21. Swati Mehrotra, Ritesh Khunyakari, Chitra Natarajan and Sugra Chunawala: *Gendered communication in technology tasks: Glimpses of group interactions*

22. Shweta Naik, Rakhi Banerjee and K. Subramaniam: *Students' use of language and symbols to reason about expressions*

23. Chitra Natarajan and Sugra Chunawala: *Introducing design and technology in school education: Legitimising multiple expressions in classroom*

24. Stella O. Odebode: *Re-examining gender balance education in agricultural science, technology and mathematics in Nigeria: An overview*

25. Kamisah Osman and Lilia Halim: *Anchoring science education towards scientifically literate Malaysian society: an exploration of children's affective psyche*

26. Shirish R. Pathare and H. C. Pradhan: *Students' alternative conceptions in pressure, heat and temperature*

27. Sridhar Rajagopalan, Vyjayanthi Sankar and Poonam Batta: *An overview of the development of learning standards for science and mathematics education:KG-8*

28. Madhav R. Rajwade, Sudhir V. Panse and H. C. Pradhan: *Probing nature of links amongst physics concepts*

29. N. Ramkumar and Sudarshan C. Panigrahi: *Acquisition of process skills by IV standard pupils through an instructional programme in environmental studies*

30. Manjula P. Rao: *Effect of concept mapping in science on science achievement, cognitive skills and attitude of students*

31. Satyawati Rawool: *Developing cognitive flexibility*

32. Perihan Sen and Ozlem Cezikturk: *What if Socrates uses Mathlets?*

33. Amit Sheth: *Science at Play*

34. Thomas Stern: *Co-operation between schools and universities as a catalyst for the professional development of teachers*

35. Kimberly D. Tanner*: Involving scientists in K-12 science education: benefits to scientists from participating in scientist-teacher partnerships*

36. Luis Tinoca: *Focusing professional development for science teachers on student learning*

37. Maria Odete Valente*: Learning to think: Lines of research in Dianoia project*

38. Keshav S. Varde: *Early exposure of pre-college students to information technology*

39. James J. Watters and Carmel M. Diezmann: *Reforming education: the pursuit of learning through authentic inquiry in mathematics, science and technology*

Appendix D
List of participants

Participants from outside India

1. Francis A. Adesoji
   University of Ibadan, Nigeria

2. Margarida Afonso
   College of Education, av Prof. Fazia de vasconceios, Portugal

3. Anjana Ganjoo Arora
   Northern Kentucky University, USA

4. John Backwell
   Goldsmiths College, University of London, UK

5. Nicole Carignan
   Department of Specialized Education (DEFS), University of Quebec (Montreal) & University of Port Elizabeth,Canada

6. Ozlem Cezikturk
   Oguzkaan High School and Bogazici University, Turkey

7. Jose Garcia Clavel
   Facultad de Economia, Dpto de Metodos Cuantitativos para laEconomia, Spain

8. Bronislaw Czarnocha
   City University of New York, USA

9. Pradeep M. Dass
   Appalachian State University, USA

10. Carmel Diezmann
Faculty of Education, Queensland University of Technology, Australia

11. Jaya Earnest
Centre for International Health, Curtin University of Technology, Australia

12. Jazlin Ebenezer
Wayne State University, USA

13. Nelofer Halai
The Aga Khan University Institute for Educational Development, Pakistan

14. Lilia Halim
Faculty of Education, National University, Malaysia

15. Barbara Jaworski
Agder University College, Norway

16. James Kakooza
Enhancement of Universal Primary Education in Kampala (EUPEK), Uganda

17. Yung Sik Kim
Program in History and Philosophy of Science
Seoul National University, Korea

18. Bodil Kleve
Oslo University College, Norway

19. Ravinder Koul
Penn State University-Great Valley, USA

20. Bracha Krmarski
Bar-Ilan University, School of Education, Israel

21. David Devraj Kumar
Florida Atlantic University, USA

22. Verdiana Masanja
University of Dar es Salaam, Tanzania

23. Michael R. Matthews
School of Education, University of New South Wales, Australia

24. Zemira R. Mevarech
Bar-Ilan University, Israel

25. Subahan Mohd. Meerah
Faculty of Education, Universiti Kebangsaan, Malaysia

26. Punyashloke Mishra
Learning, Technology and Cultural Program,
Michigan State University, USA

27. Barbara Moskal
Mathematical and Computer Science,
Colorado School of Mines, Golden, USA

28. Pearla Nesher
Haifa University, Mount Carmel, Israel

29. Odebode Stella Olusola
University of Ibadan, Nigeria

30. Kamisah Osman
School of Education, Universiti Kebangsaan, Malaysia

31. Vrunda Prabhu
City University of New York, USA

32. Susan Rodrigues
Institute of Science Education, University of Edinburg, UK

33. John F. Sowa
Ex-IBM, USA

34. Kaye Stacey
Department of Science and Mathematics Education,
The University of Melbourne, Australia

35. Thomas Stern
IFF – Faculty for Interdisciplinary Studies,
University of Klagenfurt, Austria

36. Kimberly Tanner
San Francisco State University, USA

37. Luis F. Tinoca
University of Texas at Austin, USA

38. David Treagust
Curtin University of Technology, Australia

39. Maria Odete Valente
School of Science, Departamento de education,
Universidade de Lisboa, Portugal

40. Keshav Varde
College of Engg. and Computer Science,
University of Michigan- Dearborn Campus, USA

41. Geeta K. Verma
Georgia State University, USA

42. Purvi Vora
Teachers College, Columbia University, USA

43. Marc deVries
Department of Technology Management,
Eindhoven University of Technology, The Netherlands

44. James J Watters
Queensland University of Technology, Australia

45. Orit Zaslavsky
Dept. of Education in Technology and Science,
Technion- Israel Institute of technology, Israel

Participants from India

1. Sudhakar C. Agarkar
Homi Bhabha Centre for Science Education, Mumbai

2. Senthil Babu
Dept. of Indology, French Institute of Pondicherry

3. Atanu Bandopadhyay
Homi Bhabha Centre for Science Education, Mumbai

4. Rakhi Banerjee
Homi Bhabha Centre for Science Education, Mumbai

5. Abhijeet Bardapurkar
Homi Bhabha Centre for Science Education, Mumbai

6. Swati Bedekar
SM Graphic Educational Kits, Vadodara

7. Kulwanti Bellara
Homi Bhabha Centre for Science Education, Mumbai

8. P. K. Bhattacharyya
Department of Science & Mathematics NCERT, New Delhi

9. Sheela Chacko
Spicer Memorial College, Pune

10. Ansuman Chattopadhyay
Centre for Science Education, North Eastern Hill University, Shillong

11. Beena Choksi
Homi Bhabha Centre for Science Education, Mumbai

12. Indira Choudhary
TIFR Archives, National Centre for Biological Sciences, Bangalore

13. Sugra Chunawala
Homi Bhabha Centre for Science Education, Mumbai

14. Probal Dasgupta
Centre for Applied Linguistics & Translation Studies, University of Hyderabad, Hyderabad

15. Narendra D. Deshmukh
Homi Bhabha Centre for Science Education, Mumbai

16. Patrick Dias
Multilingualism Network

17. V. G. Gambhir
Homi Bhabha Centre for Science Education, Mumbai

18. Anand D. Ghaisas
Homi Bhabha Centre for Science Education, Mumbai

19. Satyendra Giri
All India Science Teachers' Association, Kolkata

20. Chhaya Goel
Centre for Advanced Study in Education, Vadodara

21. D. R. Goel
The Maharaja Sayajirao University of Baroda, Vadodara

22. Pranita Gopal
    Army Institute of Education, Delhi

23. V. G. Jadhao
    Regional Institute of Education, Bhopal

24. Santa Ram Joshi
    Centre for Science Education, North Eastern Hill University, Shillong

25. K. Latha
    National Institute of Advanced Studies, IISC, Bangalore

26. Vinodini Kalagi
    Anandniketan School, Nashik

27. Meena Kharatmal
    Homi Bhabha Centre for Science Education, Mumbai

28. Ritesh Khunyakari
    Homi Bhabha Centre for Science Education, Mumbai

29. Sudhir N. Kulkarni
    Doodhsakhar Mahavidyalaya, Bidri

30. Arvind Kumar
    Homi Bhabha Centre for Science Education, Mumbai

31. V. D. Lale
    Homi Bhabha Centre for Science Education, Mumbai

32. B. S. Mahajan
    Homi Bhabha Centre for Science Education, Mumbai

33. Kamal Mahendroo
    Eklavya, Bhopal

34. Sindhu Mathai
Homi Bhabha Centre for Science Education, Mumbai

35. Arun T. Mavalankar
Homi Bhabha Centre for Science Education, Mumbai

36. Swati Mehrotra
Homi Bhabha Centre for Science Education, Mumbai

37. Usha Menon
NISTADS, New Delhi

38. K. K. Mishra
Homi Bhabha Centre for Science Education, Mumbai

39. Chel Madan Mohan
Dept. of Mathematics Education, Sammilani Mahavidyalaya, Kolkata

40. Srinivasan Muthusamy
GEAR Foundation (Gifted Education And Research), Bangalore

41. G. Nagarjuna
Homi Bhabha Centre for Science Education, Mumbai

42. Shweta Naik
Homi Bhabha Centre for Science Education, Mumbai

43. Manoj Nair
Homi Bhabha Centre for Science Education, Mumbai

44. M.G. Narsimhan
National Institute of Advanced Studies, Bangalore

45. Chitra Natarajan
Homi Bhabha Centre for Science Education, Mumbai

46. N. Ramkumar
National Institute of Advanced Studies, Bangalore

47. Shamin Padalkar
Homi Bhabha Centre for Science Education, Mumbai

48. Deepak S. Paranjape
Homi Bhabha Centre for Science Education, Mumbai

49. Imran K. Pathan
Homi Bhabha Centre for Science Education, Mumbai

50. Shirish R. Pathare
Homi Bhabha Centre for Science Education, Mumbai

51. H. C. Pradhan
Homi Bhabha Centre for Science Education, Mumbai

52. Anur Puniyani
Navnirmiti, Mumbai

53. C. K. Raju
Center of Computer Science / Center for studies in civilizations, MCRP University, Bhopal

54. Madhav Rajwade
Sathaye College, University of Mumbai, Mumbai

55. Jayashree Ramadas
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56. Mridula D. Ranade
Post Grad. Dept of Education, SNDT Women's University, Pune

57. Manjula P. Rao
Dept. of Education, Regional Institute of Education (NCERT), Mysore

58. T. Purushotham Rao
University of South Pacific, Suva, Fiji

59. Satyawati Rawool
P.V.D.T. College of Education for Women, Mumbai

60. Sadhana Saxena
Dept. of Education, University of Delhi, Delhi

61. Amit Sheth
Vikram A Sarabhai Community Science Centre, Ahmedabad

62. Parvin Sinclair
Indira Gandhi National Open University, New Delhi

63. V. C. Sonawane
Homi Bhabha Centre for Science Education, Mumbai

64. B. V. Sreekantan
Ex Tata Institute of Fundamental Research, Mumbai

65. Savitri Srinivasan
GEAR Foundation (Gifted Education And Research), Bangalore

66. K. Subramaniam
Homi Bhabha Centre for Science Education, Mumbai

67. Anand Swaminathan
Community Initiatives, Wipro Ltd, Bangalore

68. T. V. Venkateswaran
Vigyan Prasar, Dept. of S & T, New Delhi

69. Jyotsna Vijapurkar
Homi Bhabha Centre for Science Education, Mumbai

70. Indira Vijaysimha
National Institute of Advanced Studies, Bangalore

71. Sankar Vyjayanthi
Educational Initiatives Pvt. Ltd., Ahmedabad

72. Manish Yadav
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