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Paper Title: **Constructivist Research, Curriculum Development and Practice in Primary Classrooms**: Reflections on Five Years of Activity in the Science Processes and Concept Exploration (SPACE) Project

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Constructivist Research, Curriculum Development and Practice in Primary Classrooms: Reflections on Five Years of Activity in the Science Processes and Concept Exploration (SPACE) Project.

This paper reflects on the implications of a five year programme of research and development with non-specialist teachers of science in primary (elementary) classrooms in England. Within a constructivist framework defined by University-based researchers, groups of teachers explored the viability of a range of methods of eliciting children's ideas prior to helping children to develop their thinking in the direction of conventional scientific understanding. This research led to the development of curriculum materials, (Nuffield Primary Science) generated in a similar manner, with groups of teachers operating under normal classroom conditions. The outcomes and implications of this programme of research and curriculum development are described and critically discussed. Particular reference is made to the needs of teachers wishing to operate within a constructivist orientation, bearing in mind the constraints of normal classroom conditions.

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INTRODUCTION

The objective of the work reported here may be summarised as an attempt to explore the implementation of a constructivist approach to teaching science in elementary classrooms. The method used was a form of action-research in which researchers and teachers worked closely together to explore the practical possibilities and limits of classroom based research designed to support a curriculum innovation. Some of the thinking which gave rise to the project is reported in Black and Harlen (1993), the concern being to specify the range of concepts appropriate for a primary science curriculum. The research was dubbed the primary Science Processes and Concept Exploration (SPACE) project. This work commenced in 1986 and some of the research remains to be published. Among the products to date is a series of research reports, (Osborne et al.,1990; Osborne et al., 1991; Russell and Watt, 1990a; Russell and Watt, 1990b; Watt and Russell, 1990; Russell et al.,1991; Osborne et al.,1992; Russell et al., 1993) and a commercially produced elementary science scheme, (Nuffield Primary Science; Collins Educational, 1993). This scheme is based around a series of twelve Teachers' Guides for use with pupils aged 7-11, each related to a conceptual area. A separate Teachers' Guide relates to the 5-7 age group. Additionally, an in-service pack, a Teacher's Handbook and 36 pupil books were written to support the use of the scheme, (Black et al. 1993a and b).

Is a constructivist curriculum a contradiction in terms? If children's knowledge is regarded as individually constructed and idiosyncratic, such a conclusion might well be tempting since any attempt to define a generic path for learning would appear to be inconsistent with this assumption. However, the evidence is that, whilst unique understandings are certainly constructed, considerable commonality amongst the informal ideas which children express is frequently identifiable (Driver, Guesne et al. 1985; Black and Lucas, eds., 1993). Consequently, there is the possibility of teachers adopting both a general (content-free) set of strategies as well as those necessary to manage recurring (content-specific) ideas. The assumption is that each child generates his or her own knowledge, though the inception of that knowledge will reside in a largely common set of experiences, language, and culture. It would be surprising, given unavoidably common experiences of force and motion, for instance, if children did not share certain ideas about the nature of the forces acting on thrown objects. Considerable evidence for this view is to be found in the various reports of research (Mariani and Ogborn 1991; Bliss, Ogborn et al. 1989 and di Sessa 1988) into children's reasoning about motion.

ORGANISATION OF RESEARCH AND CURRICULUM DEVELOPMENT

The method adopted was collaborative research between teachers and University-based researchers. The teachers had no special expertise as teachers of science. They were identified by a science adviser in their Local Education Authority and an initial meeting with Head Teachers of the participating schools established the schools' willingness to collaborate. This included the possibility of teachers being released for occasional meetings. The implication was that teachers' participation was recognised and valued by their employing authorities, for whom the benefits were anticipated as being enhanced professional development. In addition, the university researchers offered participating teachers the possibility of submitting records of their involvement, of children's work and critical commentaries on classroom procedures, for accreditation towards a Certificate in the Advanced Study of Education. These features contributed to the very positive atmosphere in which the teachers' meetings and the work in classrooms proceeded.

The cycle of classroom research was as follows. A conceptual domain within which the enquiry would proceed - a researchable-sized bite - was defined e.g. ideas about growth or electricity. (The introduction of a National Curriculum with defined domains of learning later determined the precise areas to be researched.) One group of about twelve teachers then pursued enquiry within that agreed area over a period of 10-16 weeks with the support of group meetings and occasionally, classroom visits. Teachers set a context for children's initial exploration of ideas within the chosen domain. The ideas of all children were elicited after the exploratory experiences. This procedure was to avoid taking children by surprise, with its inherent danger of stampeding them into unreflective responses. A range of 'interventions' were discussed and tailored to the ideas generated. Finally, to complete the cycle, children's post-intervention ideas were ascertained. The means of eliciting ideas in a viable manner within a normal elementary classroom environment was essential to the success of the approach. Teachers also needed support from the researchers and one another in designing and managing appropriate interventions. The data generated by the project were largely in the form of children's classroom outputs. These were supplemented by individual interviews with a sub-set of children conducted by the research teams.

An attempt was made to have a sequence of teacher meetings having the following functions:

1st Meeting: The introduction and definition of the domain of enquiry; the exploration and support of teachers' own understanding of the science; the determination of an agreed set of elicitation activities.

2nd Meeting: Reporting the outcomes of the elicitation activities across the range of participating age groups of children. Discussion of broad possibilities for interventions, in the light of the kinds of ideas and sequences in ideas emerging.

3rd Meeting: Provision of feedback about the quality and efficacy of the classroom interventions designed to help children to develop their ideas in the direction of conventional scientific understanding.

4th Meeting: Critical review of the outcomes of all phases of research within the domain and summary of the lessons learned for future classroom work in the same area.

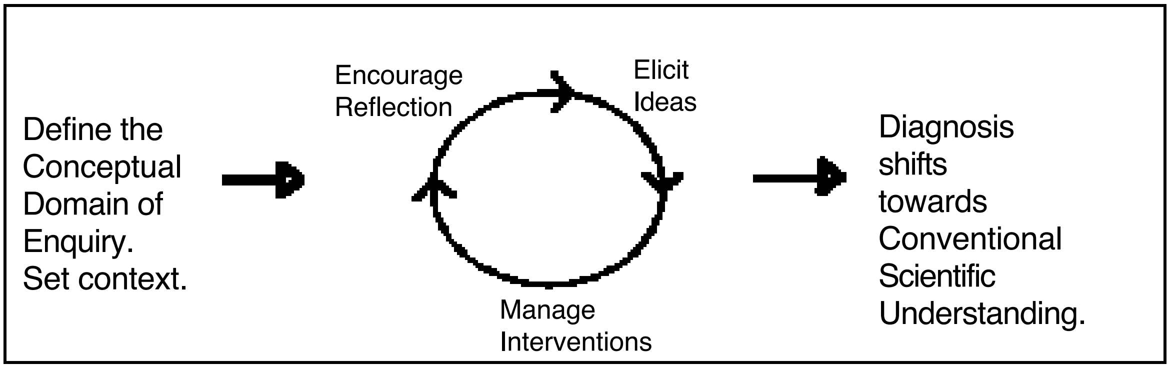
The nature of the management role which teachers were encouraged to adopt is presented schematically in Figure 1. Although the approach can be described as 'child-centred', each teacher had a clear agenda as to the direction in which children's understanding should be helped to proceed. This is not to suggest that the achievement of understanding in conventional scientific terms was the invariable expectation. The point of the research was:

* to find out the frequency and distribution of ideas prior to teaching
* to explore possibilities of helping children to develop their thinking
* to identify what quality of understanding might be reasonably expected for a child of a given age.

In other words, it was accepted that there might be limits of various kinds on children's understanding, perhaps developmental, linguistic, cultural or experiential in origin. Success in achieving progression was not defined solely in terms of the achievement of a 'complete' grasp of an idea, but more in terms of a shift in a child's understanding.

The starting point of the research cycle in classrooms was to set the context by providing experiences which would engage children and encourage them to reflect on their own understanding. Typical examples are a tank of water to start children thinking about evaporation; torches, mirrors and reflectors for exploring ideas about light; objects with which to generate sounds, etc.

Figure 1 Schematic Representation of the Teacher's Role in a Constructivist Classroom Regime.



In an attempt to operationalise the basic epistemological and pedagogical stance adopted by the project, researchers made a fundamental prescription that teachers should make every effort to listen to children and to accept their ideas as interim theories or explanations. For some teachers, even this initial orientation was a challenge to their view of science (as a body of facts) and science teaching (the direct transmission of those facts using a didactic pedagogy). Even those teachers who were able to empathise with children's views found it difficult to hold back from correcting them or 'handing over' the conventional scientific explanations of the phenomena under consideration. Some teachers felt initially that to fail to teach directly was tantamount to professional neglect. However, for many, the discovery that children held well-defined explanations for physical phenomena, albeit scientifically incorrect, was a fascinating revelation. And once the efficacy of managing learning by harnessing children's own motivation to find out and make sense of things for themselves was experienced, they tended to be won over by the approach. It was felt that the teachers of younger children, in particular, accommodated the approach more readily, perhaps because they were more accustomed to the struggle of understanding young children's point of view, given that these tend to be further removed from adult perspectives than is the case with older children.

The context setting referred to in Figure 1 included the encouragement for pupils to explore and reflect on the (preferably direct) experiences set up by the teacher. The teacher's next step was to encourage and enable children to make their ideas explicit. At this point, the expression of ideas was welcomed, all ideas being accepted as provisional. It would not be accurate to describe this activity as one in which 'misconceptions' were identified; what was being identified was the child's ideas or concepts; these are not treated as right or wrong, as 'misconceptions' or 'preconceptions', but as valued expressions which could be accepted temporarily. In the light of the ideas expressed, teachers moved children to an intervention phase in which those ideas were more explicitly treated as conditional upon supporting evidence.

Some researchers have identified the need for conceptual conflict, challenge or provocation, to engage children in a dialectical process. Doubts do exist about the effectiveness of such confrontational strategies (see, e.g. Claxton, 1993) and clearly, this is an issue needing further research. The general position of principle in the work reported here was that, to remain within a constructivist orientation, children would need to explore evidence which might support or challenge their existing assumptions. The strategy was not to confront, but to take interest in children's ideas and pursue their implications. The enterprise of seeking new evidence was stimulated and guided by the teacher, but remained within the ownership of the child. The learners' theory-building predilections were harnessed in helping them to *develop* their thinking. To do otherwise would seem to be to abandon a constructivist position. The recognition of children's need to engage with evidence relevant to their personal theories is an important feature which distinguishes the approach from guided discovery learning. The acceptance of ideas by the teacher and the class group would be conditional on supporting evidence; ideas were subjected to scrutiny and validation, often using class discussion. Some ideas may have been ephemeral; others might have been the subject of lengthy enquiry.

When class discussions were encouraged, it became obvious that some groups were accustomed to a regime in which others' ideas were treated with sceptical respect rather than scorn or disinterest. It would be very difficult for a teacher to operate a constructivist approach in a classroom ethos in which pupils were unable to share ideas, and such a regime takes time to establish. It was certainly the case that many children found the new regime puzzling. They were accustomed to teachers either providing or cuing heavily the right answer; those pupils who were used to succeeding with recall strategies were particularly perplexed. Pupils who were less accustomed to being correct tended to be more prepared to engage with the new rules and take risks by expressing tentative ideas. Pupils, as well as teachers, had to learn the procedures inherent in the new pedagogy.

ELICITATION STRATEGIES

Classroom techniques for establishing children's existing ideas can only approximate the ideal of the one-to-one Piagetian clinical interview. In such an approach the interviewer avoids leading the discussion once the focus or problem has been set and uses methods of teaching back and counter-suggestion to explore children's thinking. This approach can only be emulated in the classroom context. One of the achievements of the project was to develop techniques that were valid and reliable means of ascertaining children's thinking within such an environment. In addition, individual interviews were conducted by the university researchers with a sub-set of participating classes. These interviews were audio-recorded and formed the basis of quantitative reports of frequencies with which certain classes of ideas were encountered, as well as shifts in thinking. Some of the techniques developed and used by teachers in their classrooms are very briefly described.

- *Teachers' open-ended questioning* was an important technique and to some extent, this method was already in use. Open-ended questioning was encouraged. Questions which tend to elicit ideas were promoted, such as, 'What do you think is happening here?' Some teachers explored the possibility of roughly quantifying the incidence of ideas in a group of children via the medium of class discussion. This is only likely to be a possibility when both children and their teacher are accustomed to such a procedure, but it is a reminder that group methods and constructivist approaches are reconcilable.
- *Children's drawings as expressions of their thinking and ideas* were used extensively, (see Russell, 1993a). Care had to be taken to ensure that children appreciated that it was their ideas that were being sought, not their artistic expression and children were often asked to add or annotate drawings to show for instance, what happened to the food they ate or how the light travelled between their eyes and a book; some annotations were added by the teacher in those instances in which children lacked the writing skills to do so themselves. Picture-strip techniques evolved to cope with illustrations of changes over time, such as chemical change. Children also coped well with requests to produce a series of drawings showing changes back through geological or evolutionary time scales, using a similar

picture-strip method.

* *Class diaries or log-books* - class or group recording methods using combinations of drawing and writing pasted together as a compendium of their activities and deliberations - proved invaluable as diagnostic records of children's thinking. Log-books were essential when the events under consideration were intrinsically slow: germination and growth of plants, evaporation, decomposition, rusting, for example.
* *Sorting activities* were also widely used. For instance, children would be asked to sort sets of cards containing the names of objects and animals into living and non-living or to group foods into healthy and non-healthy. The children's groupings, and their rationale for their choices provided valuable insights into their thinking by forcing them to articulate the criteria they were using.
* *Concept mapping* was used by some teachers to explore children's understanding. In particular, clarification was sought as to the nuances of meaning understood by children with respect to the vocabulary generated during class discussions.

These means of eliciting children's ideas are within the range of any teacher with the motivation to do so, but it is the purpose for which they are used within constructivist research which is innovative. The fact that they may seem straight-forward can be taken as proof of their classroom viability. Anything complex and demanding of teachers' management time would simply not be used.

INTERVENTION STRATEGIES

As the project progressed, certain strategies which had proved their worth on several occasions, to different groups working on different concept areas, came to the fore with the familiarity of their repeated use. These strategies were discussed amongst the groups of teachers and some were refined and elaborated. As suggested earlier, questioning which changed in emphasis from open-ended to seeking justification and evidence in support of expressed beliefs was the starting point recommended for teachers moving into the intervention phase. This implies a more challenging style of questioning, but not one which should deflate or alienate children. In an affective sense, the main point is that children's own ideas remained the focus of interest, and children were found to respond to the fact that their ideas were taken seriously. Constructivism rests on the assumption that individuals generate their own theories and explanations, some of these being acquired through cultural experiences. There is no necessity to abandon assumptions about the learner's autonomy with the introduction of selected interventions. The project always described intervention most carefully in terms of 'helping children to develop their ideas' rather than 'developing children's ideas'. Such subtle distinctions in wording imply enormous differences in approach.

The essential issue was the manner in which children were being helped to extend their understandings. A resort to didacticism to 'correct misconceptions' was rejected. Instead, the over-arching strategy was to explore evidence in a form which children could engage with from their current standpoint. Evidence might be from direct experience or from secondary sources but if it was not a) relevant to the child and b) in intellectually accessible form, it was unlikely to be accommodated. By beginning with the child's hypothesis, the teacher was able to guide the work in pertinent directions and introduce other ideas for testing appropriate to the present level of understanding.

Children's learning takes place in a social and cultural context, so there need be no fear that they are being asked to re-invent or re-discover the scientific understanding of the past several thousand years. Evidence takes a variety of forms including more or less authoritative 'secondary' sources. (Constructivism in science education is sometimes too narrowly defined as being concerned only with knowledge constructed from primary sources.) A constructivist approach will include a concern to engage in transactions with children around any evidence perceived to be relevant and intellectually accessible. Children may be tempted to resort to assertion or authority to bolster their stated beliefs, until they learn something of the culture of scientific discourse. Evidence is never 'self-evident'. Rhetoric was understood as an art as much as a science in medieval culture and today's lawyers and politicians continue the tradition. Much more research is required into children's views and treatments of evidence and the manner in which they become convinced of the accuracy or acceptability of certain beliefs.

Children's own investigations of their stated ideas were encouraged when the content lent itself to empirical investigation. For example, ideas about aspects of the solar system might be difficult for children to explore directly, though even here they might be asked to generate hypotheses to be tested with scale models. Ideas about evaporation, conditions for plant growth, etc. could be more readily tested directly. This approach calls on the use of science process skills, so teachers have to be skilled in the management of scientific investigations, as well as knowing the science content. Children might be asked, 'How could you test that idea?', a more challenging response from the teacher than the initial approval.

As with all interventions, children's investigations were not expected to result in the achievement of 'complete' understanding. They might be able to reject a hypothesis, and it is argued that this result is consistent with a the idea of progression in understanding. Equally, children have to learn that a positive test does not 'prove' a hypothesis; the evidence is simply consistent with the stated hypothesis and has to be evaluated and interpreted. As suggested above, as well as the beliefs themselves, children's use of supporting evidence is in need of further research. For example, Gauld (1989) makes some interesting observations in the context of children's responses to empirical evidence about electrical circuits. He concludes,

> '*Pupils usually demonstrated a high regard for empirical data as a standard against which their ideas should be assessed*', (p79).

He also goes on to make the point that:

> '*Auxiliary assumptions or hypotheses were introduced where necessary to help to relate the various models to the observations being explained, a strategy which has been noted by Lakatos (1970) and Pinch (1985) as one of the ways scientists protect a theory from refutation by experimental data*.' (p80).

More needs to be known about the factors which cause some evidence to be persuasive and other evidence to provoke defence and perhaps entrenchment.

Class discussions and group validation was the kind of forum which seemed to maximise the benefits of investigations. The investigations tended to be carried out by small groups of children sharing similar ideas. The class discussion enabled presentations to be used as the vehicle for sharing data, interpretations and conclusions. The value derived from such discussions would be heavily dependent on the quality of management of the teacher. Child-centred approaches have been guilty of sliding into laisser faire and have consequently have been rightly criticised. The teacher's management of the discussion, to be effective, would need to be informed by a clear perception of the science knowledge towards which children are developing; it would also need to be sensitive to the kinds of ideas which children typically present: models of 'active seeing', evaporation as the disappearance of matter, and so on. Prior experience of directing such discussions would prepare teachers for the ideas likely to be expressed and permit them to rehearse strategies for maximising opportunities for helping to take thinking forward.

Language, metaphor and analogy usage should be of central concern within a constructivist approach, since language is one of the media through which transactions between individuals about meaning and evidence occur. Checking the meaning of words is another manner of discovering the nuances of personal perceptions; this applies no less to a culturally transmitted system than to direct experiences. Some ideas might be associated with vocabulary or definitional issues which may be very readily adjusted through interpretation and discussion. For example, an idea that soap 'melts' in hot water might readily be modified to an acceptance that this is a case of dissolving. As far as possible, vocabulary was clarified by illustrating cases of an object or event through direct experiences. Thus 'vibration' could be illustrated by visual, tactile and auditory modalities so that the word could be used with some degree of consensus as to what it implied. When appropriate, children collected instances of objects which illustrated a concept, as for example, 'rust'. Children's ideas of set membership could be refined through considering examples: a brown, dried up leaf was at first accepted for set membership by some young children, but rejected following discussion. It is instructive to note that this activity is no less relevant to adults' use of scientific terminology. For example, are all metal oxides to be treated as cases of rust, or only ferrous metals? Vocabulary and metaphor are intertwined. Words are the public symbols of our internal representations and some metaphors are very relevant to scientific ideas. For example, the idea that 'we look daggers' or 'cast piercing glances' implicity reinforces the notion that vision is an active process.

Learning science involves learning to see in new ways. The principal instrument for the social construction of reality is language so science draws heavily on metaphor and analogy. As Sutton (1992) argues 'selecting a new metaphor is one of the main tools for innovation in thought....Once Harvey saw the heart as a pump ....there were a host of new questions that could be investigated.U Yet the young child's vocabulary is limited and he or she often uses a restricted set of the meanings of word resulting in underextension e.g 'animal' is often used for the term mammal, or alternatively, words are overextended so the term 'melting' is used for the process of dissolving as well as melting. Consequently we must see science education as a process of inducting children into new ways of talking about familiar phenomena and provide structured opportunities for linguistic exploration. Through such explorations and interpretations, the meaning of language and ideas can be refined.

Broadening children's experience is a very familiar requirement in elementary education, more particularly so with very young children. Not uncommonly, teachers start by asking children to report to the class their personal experiences. For instance, children might be asked to report instances of evaporation which could generate instances such as fish tanks, washing on the line, puddles in the playground, reservoirs; perhaps non-aqueous liquids might be mentioned by older children. Critical consideration of these illustrations of a phenomenon may help children to broaden and abstract their ideas. The evidence which children are considering in this technique is socially propagated; each child is checking personal constructions of experiences against those constructed by peers. In the case of groups of children generating lists of 'living things', many might be surprised at the suggestion of plants, fungi, invertebrates or micro-organisms. The consequence might be a re-structuring of notions of 'alive'.

It is worth re-emphasising the aspect of social transmission which is intrinsic to this strategy, since this element tends to be overlooked in considerations of constructivist approaches. Other relevant factors include the fact of starting where children are, with the ideas which *they* express. This principle ensures that children feel a sense of ownership of the discussion, so there is involvement and a sense of relevance to the context of their lives.

Meta-cognitive approaches to representations describes the process of encouraging children to reflect on their own and others' ideas, principally in the form of drawings. As indicated earlier, drawings were used extensively as an elicitation medium. It was a particularly successful technique because it enabled ideas to be expressed which might have been difficult for children to articulate verbally. In addition, the physical presence of the drawing facilitated further elucidation of what it was that the child was attempting to express: the drawing could be interrogated. As a diagnostic tool, drawings also have the great virtue of permanence. They could be annotated with clarifying or explanatory remarks by pupils or by teachers.

Expressing *ideas* in the form of drawings was a technique which children had to learn. It is freely admitted that the act of articulating an idea in this form causes the child to focus on and explicate the concept whereas previously their thinking may have been semi-intuitive and lacking an articulated form. (The same is true of any interview: being asked questions and having to frame a response forces children to commit themselves to explicate intelligibly.)

It is the principle of reflecting on expressions of ideas, the meta-cognitive dimension requiring children to think about how they are thinking, that is exploited in this strategy. *Expressing* an idea is the first step; *reflecting* on their own ideas, thus making them 'self-conscious' might be seen as a second level; *comparing* their own ideas with those of others extends the process of critical reflection further still.

In what manner can this be described as a constructivist strategy? In a sense, children are themselves being asked to behave as constructivists as they articulate and compare different representations of phenomena. Science education makes widespread use of diagrammatic representations. Children's appreciation of the origins and meaning of such forms is likely to be enhanced by the process of engaging in their own attempts to represent ideas. It is assumed that, having struggled to present an intelligible pictorial representation of e.g., sound travelling, children will be in a better position to make sense of other representations, including formal representations of longitudinal or transverse waves. It would seem to make sense, pedagogically speaking, to choose the right moment to make such diagrams available, such decisions being informed by the likelihood of children finding the ideas relevant and accessible.

Making imperceptible events perceptible is a way of accommodating the theoretical and practical knowledge that young children find direct sense impressions more accessible and more convincing as sources of evidence than abstract information. Much school science is concerned with abstract phenomena. One position commonly adopted is to push such material to the later years of schooling. There are counter-arguments that some abstract ideas underpin ideas which are too important in constructing foundations to defer to later years. A compromise is to seek ways in which abstract ideas may be made more accessible to children. For example, the sense of smell can often be used to detect the presence of material which is too small to detect visually. Such experiences may be used to confirm the existence of material in particle form. Confirming the spherical shape of the Earth by observing the visible curvature on the horizon is another example.

The essence of this strategy is to make what would otherwise be abstract phenomena concrete. Occasionally, as in time-lapse photography used to speed up otherwise imperceptibly slow events such as plant growth, technical mediation rather than direct observation is used. Piaget noted the importance of concrete experiences in intellectual development. Bruner's notion of enactive imagery is a parallel acknowledgement of the persuasive impact of tangible experiences. In the case of the latter, there are no assumptions about invariant stage-developmental sequences.

CLASSROOM RESEARCH AND CURRICULUM DEVELOPMENT

The similarities and contrasts between the research and curriculum development are summarised in Table 1. After the domain had been selected, researchers would work with the teachers using a mix of elicitation techniques - interviews, drawings, writing - to collect data on children's thinking. The data would then be discussed with teachers and a set of intervention strategies evolved (see, e.g. Osborne et al. 1992). When these activities had been completed - this varied from 6 to 12 weeks - a phase of post-intervention elicitation was undertaken and then a lengthy process of data analysis completed to examine what ideas prevailed, what learning gains had been achieved and what intervention strategies seemed to be fruitful.

The cycle of constructivist teaching activity, as summarised in the second column of Table 1, maps onto the cycle of research activities almost perfectly. This point emphasises the relevance of the research cycle to teachers' classroom activities. The methods and aims of researchers or curriculum developers and teachers may differ, but it had always been the intention to conduct applied research of relevance to teachers' practices and the possibilities of supporting children's learning. The structure for the development of curriculum materials was able to emerge from the experience of the research in a coherent manner.

Full details of the research outcomes can be found in the published reports. Certain aspects of children's thinking were significantly improved in the direction of scientific understanding while others remained untouched by the interventions. Some intervention work had significantly better outcomes with children of different ages. Controlled experiments to contrast this approach with others were deliberately not undertaken as this research aimed to explore the problems, possibilities and issues raised by a significantly different approach to pedagogy. In that

Table 1. Cycles of Research and Cycles of Classroom Practice

Research	Curriculum Materials
Select research domain	Set curricular context
Exploration	Orientation experiences
Elicitation	Find out existing ideas: Diagnostic assessment
Intervention	Teaching/learning experiences
Post-intervention elicitation	Diagnostic assessment
Analysis of data and writing	Review and planning further differentiated teaching/learning experiences

many of the overall effects were positive, such a method does have clear value and legitimacy as an approach to science education. A more experimental approach would have been unnecessarily restrictive, premature, and could have undermined the ecological validity of the research.

The success of the research led to a curriculum development project to produce materials for the teaching of elementary science based on the same approach. Success in this instance was perceived to reside in the enthusiasm amongst teachers for the approach, the extent to which pupils were engaged and enthused, the intrinsic interest of the ideas elicited from children and the light these threw on the nature of their understanding and development; the diagnostic value of ideas for informing further classroom activities and the positive and innovative intervention strategies which had been developed were also recognised.

DEVELOPMENT OF CURRICULUM MATERIALS

The basic framework of the curriculum materials matches the framework of the research. However, while the cycle of research activity unfolded over a period of weeks, with all teachers working in approximate synchrony, the expectation would be for similar formative cycles to take place at a pace determined by children's rather than the project's needs. Some classroom cycles happen in minutes or even seconds, as a teacher engages in dialogue and checks meanings and perceptions of events with a pupil. Other formative cycles might take days or weeks to come to maturity, as is the case, for example, when children engage in investigations of events such as plant growth.

As with the research, development proceeded through collaboration between the research team, which drafted material, and groups of teachers who tried out the approach. Some of the teachers had participated in the research, but not all; to some, the whole approach was novel. Meetings were convened after teachers' attempts at implementation. Criticisms and suggestions for amendments were discussed and the structure and organisation of the materials gradually emerged. The emphasis was on the development of materials to support teachers' rather than pupils' materials, though the latter were also written as secondary source materials.

The needs of teachers wishing to adopt a constructivist approach to teaching science can be summarised as follows:

* a curriculum which supports progression
* elicitation strategies and techniques
* intervention strategies
* domain-specific knowledge about pupil progression
* generic knowledge about conceptual development
* background science knowledge
* classroom management skills to implement the classroom strategies

If a constructivist approach to pedagogy is to have any practical possibility of being implemented, it must provide a set of elicitation techniques that serve as classroom tools to explore the nature of children's thinking. Each Teacher's Guide contains an early chapter suggesting strategies for orientating children to the domain under investigation and many suggestions for investigating what understanding children have of the phenomena. These ideas draw heavily on the research project and in essence consist of specific applications of the kinds of elicitation activities discussed above. It is expected that as teachers become familiar with such generic approaches, they will invent their own. The Guides can be thought of as having built-in obsolescence.

The essential problem for many elementary teachers is *evaluating* the child's thinking. This issue has two dimensions: firstly what does the child's writing or drawing say about the theories and ideas they hold? What is the incidence of various ideas within the class? Secondly, given that the overwhelming majority of elementary teachers lack formal science education post-16, what is the conventional science and what kind of relationship exists between that science and children's views? To assist teachers make this evaluation, two pieces of support material were provided - a chapter which contained typical responses to the suggested elicitation activities with interpretations and a final chapter which summarised and explained the background science of the domain for the teacher.

Once the teacher has succeeded in making some diagnosis of the developmental position of a child, then he or she is then faced with the issue of providing appropriate learning experiences for that child. Two issues are raised here - the kind of understanding and attainment it would be reasonable to expect a child to achieve and the learning experiences which would enable the development of such an understanding. These are the essential questions facing all curriculum developers. A distinctive feature of the Nuffield Primary science materials is the provision of a range of learning experiences with the prescription that teachers should use the children's idea as the criteria for their selection.

Finally, the curriculum materials provided a chapter to assist with the assessment of children's learning. This exemplifies different qualities of pupils' ideas with discussion and interpretation. In this way, an approach to diagnostic assessment is illustrated as well as specific instances of progression in thinking within particular conceptual domains. The view taken by the project was that diagnostic assessment should be a routine teaching element serving formative purposes in evaluating children's thinking and determining appropriate learning experiences. The examples of children's work also provided teachers with bench marks for assessing their own children's work, particularly with reference to the levels of attainment expected by the English national curriculum, (DES, 1991). The cycle of activity encouraged by the Teachers' Guides is that summarised in Figure 1.

REFINING THE EPISTEMOLOGY AND PEDAGOGY

The development of curriculum support materials for teachers is not an enterprise that can afford to wait until all the research, supporting theory and classroom trials have been conducted to everyone's satisfaction.

Pragmatically, a curriculum structure is in place in England and Wales. Teachers are teaching, children learning. The Nuffield Primary science scheme incorporates one group's best efforts at supporting a constructivist approach in primary schools. It is not claimed that this is the last word on the subject. It may be instructive to consider what more might be done and what more might be achieved.

Research on children's thinking and its development is still an essential part of research in this domain. Science education at present bears many similarities to walking through a moonlit forest - there are many obstacles and little light to be guided by. Better descriptions of the journeys undertaken by children through this dimly lit landscape will help us to provide more accurate and effective guidance to teachers and their students. A number of issues emerge which constructivist approaches to teaching and learning must address if they are to have greater impact within the school curriculum.

Firstly Ausubel's description of pre-existing ideas as being remarkably resistant to change is in danger of becoming a cliché, if not so already. It may be less than fruitful to expend effort in an attempt to prove whether or not this assertion is the case. Undoubtedly, some ideas are both prevalent across populations and cultures and long-standing across age groups. Popular ideas about forces - that a projected object travels until it runs out of push, for example - provide convincing evidence of the ubiquitous and persistent nature of some such ideas which, as Wolpert (1992) has argued, are reinforced daily by commonsense reasoning. Other ideas might seem more ephemeral, though commonly encountered; they might be a product of developmentally or experientially limited capacities. For example, the 'clashing currents' (Cosgrove, Osborne et al. 1984) electrical model may simply be an attempt by a child to model the behaviour of electrical circuits in terms of ideas of mixtures and ingredients where 'positive' and 'negative' electricity are seen as the two components necessary to make a bulb light. Exposure to experiences and instruction which does not utilise such language may simply lead to the decay of such children's thinking.

The point of this discussion, where it is taking the argument, is that it seems to be at least relevant, and quite probably critical, to consider the *sources* of ideas when considering how or why those ideas might change. Ideas have origins; they have sources. They are confirmed to the satisfaction of the believer by evidence of some kind. Evidence may vary in kind, in power and in its frequency of occurrence and replicability. And even if evidence presented to the child seems 'plausible, intelligible and fruitful' (Hewson and Hewson 1984), it is unlikely that everyday experiences will be analysed from this framework if they are de-contextualised in the move to the classroom. Science teaching should endeavour to concern itself with everyday and ordinary phenomena, using familiar rather than specialised materials.

A fuller discussion of the sources of children's science representations is presented elsewhere, (Russell, 1993b). To summarise briefly, it is suggested that representations can be thought of as being constructed in three main contexts or information networks:

- direct sensory information, providing the learner with intuitive data, as for example about motion, forces, and the plethora of everyday experiences researched by Piaget, (Piaget, 1929).
- culturally transmitted representations though language, metaphor, myth, folklore, etc. which carry the power of authority of the culture in which an individual develops, (Luria, 1976).
- direct instruction in formal settings, a formal subset of culturally transmitted ideas. The separation is justified on the grounds of the affective differences, the self-conscious nature of the instruction and the range of evidence which is brought to bear on the learner.

Children may carry representations from one, two or all three of these sources which may be congruent or in conflict. To some extent, researchers' interests can be identified with particular sources of knowledge representation.

For example, children's representations relating to motion and dynamics are often seen to be founded on intuitive experiences. Within this area, the theory of Bliss, Ogborn et al. (1989) advances two possible agencies of causality, support and effort. Three possible sources of effort resulting in motion are suggested:

(i) Effort of another agent *on* the object
(ii) Effort generated *by* the object
(iii) Effort *of* the object. This is effort preserved within the object which sustains motion until it is used up.

Presuming that the schema associated with motion is the most well-established for the young child, it is highly likely that they will also resort to this when asked to explain phenomena in light and electricity. Hence when asked to explain how we see a book, the notion of *support* offers no assistance and, since the object is clearly static, neither does the idea of *effort by the object* or *effort of the object*. However the *effort of another agent* on the object does offer a schema for explanation. The individual, as the agent, looks to the object to see it and in so doing, exerts effort which is towards the object. The use of such a schema would then explain why children and everyday language embody the notion that vision is an active process from viewer to object.

Theory building at this level would seem to be necessary to take constructivism in science education forward so that it has greater explanatory and predictive value. The benefits are likely to reside in a better understanding of the learner's 'logic', the reasoning behind their ideas. A better understanding of how ideas came into being might provide pointers for more appropriate or precisely managed interventions. The example cited relates to intuitive schemata; similar detailed approaches to children's handling of representations embedded in language, metaphor, and other forms of knowledge made available by 'vernacular cultural osmosis' also need to be generated.

EPISTEMOLOGICAL CONSIDERATIONS

At a philosophical level, one of our concerns is the epistemology of Constructivism. Essentially epistemology has a methodological and ontological component setting out to answer the dual questions of 'what we know' and 'how we know'. Any education in science also attempts to address these questions (Ogborn 1988). The focus of constructivism so far has been not so much the genesis of the child's epistemology but the product, and more attention needs to be paid to how the child comes to generate these ideas and representations which are now extensively documented.

At the level of elementary school science education, much work is concerned with extending the range of phenomenological experiences, that is, what children *know of*, and *about* the world. Our approach was to encourage children to undertake a process of empirical abstraction of their experiences to enable the formulation of inductive generalisations. Thus all electrical devices need two wires to make them work - all living objects move and feed etc. In addition, science education throughout all ages attempts to provide an experience of 'how we know', and, in our work, children were encouraged to formulate simple hypotheses and to undertake scientific investigations by gathering and examining data to see if the patterns to be found therein confirmed or refuted their hypotheses.

On one level, such an approach is well-suited to elementary school science education enabling the young child to construct schemata of objects and their interactions. This process of conducting investigations encourages simple inductive generalisations. Yet, this is not a complete model of science - real science is theory-constitutive in the sense that

> '*the logico-mathematical operations of the individual are attributed to objects; that is they are being read into rather than read off from the objects*.' (Rowell and Dawson 1989).

A simplistic reading of a constructivist epistemology which sees learning in science as a process of empirical abstraction in which pupils 'make sense of their experiences' (Asoko, Leach et al. 1993) is in danger of presenting a naive inductivist model. For within the elementary school curriculum, there are ideas about which no amount of empirical abstraction will enable the child to formulate the accepted explanation. Thus day and night happen because the Earth spins, not because of the more self-evident interpretation that the Sun moves and we would offer the critique that constructivist approaches to the curriculum, including our own, have failed to resolve satisfactorily when and how children should come to know such ideas effectively.

We would like to argue that a more comprehensive theory would include some of the general notions of genetic epistemology which sees human thinking structured by the mental processes available to the epistemic subject. Such a position is consistent with that taken by Rowell and Dawson (1989) who distinguish between constructive and inductive generalisations. Constructive generalisations are based on explanatory principles which explain and subsume lower level inductive schemata. These form the basis of much introductory science, are based on observables and are the essential foundations from which higher level explanatory schema are formulated. For instance, a knowledge that all metals conduct electricity is an essential element in developing the electronic theory of conduction. The important distinction is that constructive generalisations are models and, though they may be confirmed by observations, they cannot be directly constructed by that means as they require a degree of creative imagination. Their understanding also requires the cognitive ability to manipulate abstract symbolic representations. The inclusion of such a perspective is essential for the guidance of the curriculum developer and teacher in making decisions about matters of content and sequence.

From a psychological perspective, the Ausubelian psychology which underpins much constructivist work, including ours, is valuable in placing an emphasis on the need for the learner to be active and for learning to be 'meaningful'. This perspective gives pre-eminence to processes which encourage the elicitation and negotiation of meaning. However, Ausubel's description lacks an elaboration of the intellectual skills necessary for meaningful learning and only White (1988) has elaborated a fuller theory. He argues for a perspective that requires schools to turn from sifting knowledge and attend more to its production. In a world where didacticism is still the essential model of teaching and learning, the case for such an argument is powerful and the SPACE research is one contribution in this direction. However, as a cautionary note, it is worth remembering that people are different and every individual takes a unique journey to becoming an epistemic subject both in terms of the experiences and their preferred learning styles (Kempa and Martin-Diaz 1990a, 1990b). Thus a more valid constructivist position would be to see the learning process as organic, dependent on the individual's biography, the teacher drawing on a wide and diverse range of strategies to meet the student's needs. Different people may need, or benefit from, different treatments.

LOOKING FORWARD

The first priority of the work reported here was unashamedly pragmatic in the sense that payoffs for more effective teaching and learning were sought. In educational research, teachers go on teaching while ontological and epistemological matters are being debated and researched. This is how it must be; the theoretical issues were grounded in practice. Indeed, given current assumptions about the manner in which psychological processes must be seen as context-specific, the approach represents good practice. Every attempt was made to subject all assumptions to theoretical scrutiny and this process is continuing. Some of the research remains to be reported. The use of the curriculum materials will be monitored and no doubt further insights will occur.

Continuing in the pragmatic vein, the notion of progression in understanding is being pursued. The emphasis of the research has been on pupil understanding, but it is acknowledged that this is just one element to be considered. The skills necessary for teachers to adopt a successful constructivist approach have been alluded to and these also are in need of more detailed research. Other groups have contributed to the debate on the role of teachers' science understanding and pedagogical knowledge and the impact of these on their teaching of science, (Bennett and Carre, 1993). At the philosophical end of the discussion, their is a lively challenge to the essential nature and plausibility of constructivism, (Suching, 1992). Constructivism has already had an enormous impact on science education at all levels but some theoretical problems remain to be addressed. There is a lack of consensus as to what, precisely is understood by the term and its implications for classroom practice. The SPACE research and the Nuffield Primary Science materials constitute one approach towards exploring the implications. There remains much to clarify through research and debate; an exciting prospect.

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