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Constructivism’s new clothes: the trivial, the contingent, and a progressive research programme into the learning of science

Abstract

Constructivism has been a key referent for research into the learning of science for several decades. There is little doubt that the research into learners' ideas in science stimulated by the constructivist movement has been voluminous, and a great deal is now known about the way various science topics may commonly be understood by learners of various ages. Despite this significant research effort, there have been serious criticisms of this area of work: in terms of its philosophical underpinning, the validity of its most popular constructs, the limited scope of its focus, and its practical value to science teaching. This paper frames this area of work as a Lakatosian Research Programme (RP), and explores the major criticisms of constructivism from that perspective. It is argued that much of the criticism may be considered as part of the legitimate academic debate expected within any active RP, i.e. arguments about the auxiliary theory making up the 'protective belt' of the programme. It is suggested that a shifting focus from constructivism to 'contingency in learning' will allow the RP to draw upon a more diverse range of perspectives, each consistent with the existing hard core of the programme, which will provide potentially fruitful directions for future work and ensure the continuity of a progressive RP into learning science.

Constructivism’s new clothes: the trivial, the contingent, and a progressive research programme into the learning of science

Introduction

This paper is about 'Constructivism' in Science Education (CiSE): its nature, the common criticisms, and its possible future. Constructivism has been the major referent for exploring learning in science for some decades, and Matthews refers to the influence of constructivism “as if a period of Kuhnian normal science has descended upon the science and mathematics education communities” (1993, p.363). CiSE is something of a diverse movement - certainly in terms of claimed philosophical underpinning - and, indeed, there is no clear boundary allowing definitive demarcation of the 'movement'. Yet the importance and influence of CiSE make it worthy of attention, and the criticisms that, for example, constructivist chemistry educators base their work on a confused philosophical position (e.g. Scerri, 2003), and that CiSE may be seen as a movement that has little more to contribute (Solomon, 1994) deserve consideration. Here, CiSE is considered from the frame of Lakatosian Research Programmes (Lakatos, 1970, 1978), and a different view is taken: that CiSE should be seen as part of a progressive research programme (RP) exploring learning in science.

Constructivism in Science Education

Identifying a research field - teaching and learning science

Science Education is a relatively young area of academic scholarship (Jenkins, 2000), concerned with the teaching and learning of science; one that has also been seen as making up part of a wider 'domain of inquiry', that “seeks to understand the dynamics of the growth of scientific knowledge” (Duschl & Hamilton, 1992, p.7.)

The origins of Constructivism in Science Education

In 1978 Driver and Easley wrote about the learner’s active role in constructing their personal knowledge - thus the term ‘constructivism’ came into common use in Science Education. This area of research is also labeled as the Alternative Conceptions Movement (Gilbert & Swift, 1985). A particular feature of work in this tradition was the significance (and so status) assigned to learners' ideas, an aspect that has been the basis of one of the main areas of criticism of CiSE (discussed below).

A major influence on CiSE has been the work of the 'genetic epistemologist' Piaget. Piaget published extensively, showing that the young child’s thinking about the world may seem illogical, irrational and even contradictory to adults, and that children who have not undertaken formal instruction might still have constructed their own ideas about phenomena they experience in the world (e.g. Piaget, 1973{1929}). Piaget believed that knowledge is formed by operating on perceptions with logico-mathematical frameworks (Piaget, 1972{1970}). Pope and Gilbert (1983) have described the “essence” of Piaget’s epistemology as being “constructivist and relativist” (p.196). The relativism tag has not endeared constructivists to some critics.

The psychotherapist George Kelly’s (1963{1955}) who built a theory of personality that he called ‘personal construct theory’ (PCT) was also influential. Kelly described his position as ‘constructive alternativism’, and emphasised the way an individual’s knowledge was provisional. Kelly’s central metaphor was of man-the-scientist (p.4), a notion reflected in Driver’s focus on the pupil-as-scientist (Driver, 1983).

The influence of constructivism in science education

In 1978, Driver and Easley described work on learners’ ideas about science as “usually small scale and scattered” (p.77). However, in 1982 Gilbert (UK), Fensham (Australia) and Osborne (NZ) published an influential paper considering 'children's science', and the various possible outcomes when children received formal instruction in the topics where they already had established ideas. In the following year, Driver's ‘The Pupil as Scientist?’ (1983), was published as well as two of the key papers setting out much of the CiSE programme (Driver & Erickson, 1983; Gilbert & Watts, 1983). Only two years later, two edited volumes discussed results from a range of core science topics (Driver, Guesne & Tiberghien, 1985a; Osborne & Freyberg, 1985).

Over a period of a few years, the study of learners' ideas about science topics developed into a major international research activity. This produced a vast literature on learners' understanding of science (Carmichael et al., 1990, Gilbert, 1994). A popular book appeared reviewing findings in all the main topics taught at secondary school level (Driver, et al, 1994). By the mid 1990s, constructivism had become an explicit referent for science teaching (Tobin, 1993a), so that major texts on teaching and learning science were branded as taking a 'constructivist approach' (Fensham, Gunstone & White, 1994) or a 'constructivist view' (Mintzes, Wandersee & Novak, 1998). Constructivism in science education was seen as a worthy focus of books in its own right (Tobin, 1993b; Matthews, 1998), and was described as being 'dominant' (Erickson, 2000, p.280), if not ubiquitous (Jenkins, 2000).

Criticisms of CiSE

There has been a good deal of criticism of research undertaken in the CiSE tradition:-

- *The incoherent philosophical position of the CiSE movement*: there has been an active debate concerning what is meant by constructivism as applied in Science Education. The flavour of some of this debate is illustrated by the conclusion to a paper by Suchting (1992, p.247) who characterised the version of constructivism presented in an influential 1989 paper by von Glasersfeld as "unintelligible", "confused" and unsupported. One area of criticism is the (real or perceived) adoption of a relativist stance on knowledge (Matthews, 1993; Scerri, 2003).,
- *CiSE uses invalid theoretical constructs*: there has been criticism of both the validity of constructs used in the field, such as 'alternative conceptions' (e.g. Millar, 1989; Claxton, 1993; Solomon, 1994), and of writing which does not clearly distinguish between the structure of an academic discipline, cognitive structures inferred in learners' minds, and researchers' representations of aspects of learners' thinking (Phillips, 1987, p.139).
- *CiSE marginalises the social perspective*: much work undertaken in the constructivist tradition sees the learner as an isolated individual constructing

personal knowledge in a social vacuum, without consideration of the very real influence of others on the learning process (Solomon (1987, 1993b).

- *CiSE does not inform teaching*: Solomon suggested in 1994 that the 'jury' was still 'out' on the efficacy of the teaching approaches recommended by CiSE research (1994, p.11), and Millar (1989) argued that the constructivist model of learning has been (inappropriately) associated with a particular model of instruction.
- *CiSE has monopolised resources in the field*: Johnstone has publicly suggested that CiSE has been given disproportional attention in terms of its potential to inform effective science teaching, and suggested that an information-processing perspective (Johnstone, 1989, 1991) would be more fruitful. Solomon has warned that "if constructivism obscures other perspectives, either by its popularity or its blandness, that could be damaging" (1994, p.17).

Framing CiSE as Lakatosian RP

Research programmes in science and science education

CiSE has been acknowledged as "something of a research orthodoxy within science education" (Jenkins, 2000, p.7), and has been described in terms of a Kuhnian paradigm (Matthews, 1993; Solomon, 1994). It is considered to be more fruitful here to frame CiSE in terms of a Lakatosian RP (cf. Watts and Pope, 1982; Gilbert and Swift, 1985; Erickson, 2000).

Lakatos initially proposed 'scientific [sic] research programmes' as a methodology for analysing the history of the 'growth' of knowledge in the *natural* sciences (1970), but here I am applying this approach to a *social* science (education), and this deserves comment.

It would be possible to argue that educational research, appropriately undertaken, could be considered to be 'scientific' in terms of Lakatos' notions of the demarcation between science and pseudo-science (Lakatos, 1978{1973}). Whilst such a line of argument has some credit, it is not suggested here that research in science education is or should be considered part of the *natural* sciences.

However, Lakatos himself discussed aspects of sociology and psychology in terms of this perspective (i.e. that "… Marxism, Freudianism, are all research programmes" p.5), and suggested that the 'methodology' of research programmes was suitable for application "to any normative knowledge, including even ethics and aesthetics" (Lakatos, 1978{1974}, p.152, n.5).

Research within CiSE has often focused on the ideas and learning of individuals, and has drawn on the idiographic tradition of research common in social sciences; but it has always sought to produce models of widespread applicability (e.g. Gilbert & Watts, 1983, Driver, 1989). The complexity of the phenomena studied (learning), and the practical and ethical issues concerned with working with students, has often required approaches that involve in-depth study of small samples of willing volunteers, by researchers who are intimately involved in the construction of data (e.g. through interviews). This means that research outputs cannot claim to be fully objective or representative, and individual differences (between learners) do not allow all-encompassing models of universal applicability. Nevertheless, CiSE is a programme that seeks to develop models that have utility value for science teaching, and is therefore a normative activity. Although there is often a significant gap between the conclusions of individual studies, and the level of guidance that usefully informs teachers, this should be seen as a methodological issue for the programme rather than a fundamental chasm (Taber, 2000a).

Lakatos presents his methodology as a means of evaluating RPs across a broad range of academic disciplines. The argument here is not that science education is part of science, but rather that the methodology of scientific research programmes provides an analytical tool that allows judgments to be made about the viability of research traditions. Framing CiSE as a RP provides a perspective for 'taking stock' of this area of research and evaluating the significance of the criticisms outlined above.

The main concepts Lakatos introduces to characterise a RP are the hard core, protective belt, and positive and negative heuristics. The hard core is a set of assumptions that is accepted as fundamental to the research programme. The protective belt is the auxiliary theory that scientists construct to explain phenomena. These theories are open to critical review, but must be consistent with the hard core. The heuristics direct scientists by giving them 'methodological rules' to follow in carrying out their work: the negative heuristic protects the hard core (by indicating "what paths of research to avoid"), and the positive heuristic outlines the development of the protective belt (by indicating "what paths to pursue") (Lakatos, 1970, p.132). Lakatos thought that as there is always room for data to be incorrect or misinterpreted - "clashes between theories and factual propositions are not 'falsifications' but merely inconsistencies." (p.99). So theories should only be disregarded when a more fruitful alternative is able to take their place. i.e. a RP with greater "heuristic power" (p.155) or "excess truth content" (Lakatos & Zahar (1978{1976}, p.179).

As a RP is a "series of theories" demonstrating "a remarkable continuity" (Lakatos, 1970, p.132), it is perfectly possible for theory to change within a RP providing that the developing theory remains true to the hard core of the programme (Lakatos & Zahar (1978{1976}, p.179). A progressive RP needs to move forward by developing its (auxiliary) theories, but not in a purely *ad hoc* manner to patch-up a match with new findings, but to also provide new predictions that can be corroborated empirically. A programme is considered 'progressive' if it leads to new facts, and 'degenerating' if new theory is added only provided to explain what is already known: (Lakatos, 1978{1973}).

According to Lakatos, the seeds of a RP are present from the beginning, as it already has "heuristic power" (Lakatos, 1970, p.175). However, Lakatos cautions that establishing a progressive RP may "take decades" (Lakatos, 1978{1973}, p.6).

Framing CiSE as a research programme

If the case that CiSE can fruitfully be considered as a Lakatosian RP is to be convincing, then it should be possible:

a) to identify a 'hard core' of basic assumptions for the constructivist programme;

b) to identify elements of a positive heuristic directing research in the field;

c) to demonstrate that key aspects of the positive and negative heuristics were present from the establishment of the programme.

In terms of the last point, it is particularly interesting to note that as early as 1985 it was possible for Gilbert and Swift to set out "towards" a provisional Lakatosian analysis, identifying as the hard core:

1. The world is real;
2. All observations are theory-laden;
3. Individuals use personally appealing explanatory hypotheses to cope with events in their environment;
4. The individual tests these hypotheses through interaction with reality against personally appealing criteria;
5. Reality provides guidance as to the adequacy of these hypotheses so tested;
6. When hypotheses are judged inadequate by such testing, either the hypotheses or the test criteria by which they were judged are modified or replaced.

The hard core of the RP

Twenty years on, there are a number of principles that would generally be considered to be axiomatic by those who have been involved in the CiSE programme. I would propose the following elements for the hard core of the RP.

1. *Knowledge is constructed by the learner, not received*. This is the essence of the constructivist position. It is worth noting that in itself this statement makes no comment on the extent to which knowledge constructed does or indeed could, represent some external reality.

2. *Learners come to science learning with existing ideas about many natural phenomena*. This statement is clearly supported by the vast corpus of research into learners' ideas showing that learners' hold prior knowledge relevant to many science topics.
3. *The learners' existing ideas have consequences for the learning of science.* This statement provides the justification for investigating learners' ideas within the context of educational research. As knowledge is constructed, the existing knowledge structures act as the starting point for further learning.
4. *It is possible to teach science more effectively if account is taken of the learner's existing ideas.* Although not every research study from within the programme might have an explicit connection to teaching, the overall body of knowledge being developed is expected to inform pedagogy.

5. *Knowledge is represented in the brain as a conceptual structure.* In some way the brain of a learner is able to represent information in a stable and non-random way.

6. *It is possible to model learners' conceptual structures.* There is also an assumption that we can model (i.e. re-re-present) these re-presentations (sic) in some way that can usefully inform teaching.

7. *Each individual's conceptual structure is unique.* Driver and Easley (1978) felt it was important to look in detail at learners' ideas, "which arise from students' personal experience of natural events and their attempt to make sense of them for themselves", using "idiographic studies … [where] the focus is on an individual's personal experience" (p.68).

The Positive Heuristic

Lakatos' suggested that "in the positive heuristic of a powerful programme there is, right at the start, a general outline of how to build the protective belts" (1970, p.175). For example, two themes that run through the CiSE RP are already present in Driver and Easley's 1978 paper. One is the issue of the stability of alternative frameworks, the other the extent to which particular alternative frameworks, as the constructions of individuals, are specific to those individuals, or may share key features with the frameworks of other learners.

The assumptions of the CiSE RP, as set out above, would seem to imply a set of broad research questions for the programme. In Table 1, the axioms of the programme are presented, alongside key areas of research activity implied by each axiom.

axiomatic assumptions (forming the hard core)	broad research questions (informing the positive heuristic)
1. knowledge is constructed by the learner, not received	how does knowledge construction (i.e. learning) take place?
2. learners come to science learning with existing ideas about many natural phenomena	what ideas do learners' bring to science classes, and what is the nature of these ideas?
3. the learners' existing ideas have consequences for the learning of science	how do learners' ideas interact with teaching?
4. it is possible to teach science more effectively if account is taken of the learner's existing ideas	how should ['constructivist'] teachers teach science in view of 1-3?
5. knowledge is represented in the brain as a conceptual structure	how is knowledge organised in the brain?
6. It is possible to model learners' conceptual structures	what are the most appropriate models and representations?
7. Each individual's conceptual structure is unique	how much commonality is there between learners' ideas in science?

Table 1: Suggested Hard Core and Positive Heuristic for the CiSE RP

The protective belt

For Lakatos, the 'negative heuristic' prevents questioning of the fundamental features of the RP, i.e. the hard core. The protective belt consists of all the theories developed in the RP that, whilst consistent with the hard core, are not necessary to it. These auxiliary theories can be changed to provide new theory still consistent with the hard core, but also matching new data. From this perspective, some of the criticisms of CiSE may be understood as legitimate scholarly debate within the protective belt of the RP.

Section 3: Considering the criticisms of CiSE from within the RP frame

Criticism 1: The philosophical position of the CiSE movement

CiSE has been criticised for being founded upon a relativist (and therefore inappropriate) view of knowledge, viz. constructisivm, which sets learners' ideas to be of equal validity to currently accepted scientific knowledge (e.g. Millar, 1989; Matthews, 1993; Scerri, 2003). Many of those labelling themselves as constructivists take the view that the 'objects' that they study are human constructions, and that the significance of such constructions derives purely from meanings people give them (Gergen, 1999). However, it has been noted that "the term constructivism is used with a number of distinct and sometimes contradictory shades of meaning across the social sciences" (Potter, 1996, p.35; Good et al, 1993), for example, being adopted by some to describe the broad movement of workers undertaking qualitative, interpretative research (e.g. Beld, 1994, p.99).

Of particular significance for the present discussion is whether constructivism is seen as being about (a) how learning occurs, or (b) the nature of human knowledge. Von Glasersfeld (1989, 1993) has made the distinction between what he labeled as trivial constructivism and radical constructivism. (cf. psychological vs. social constructivism, Phillips, 1997; cognitive vs. metaphysical constructivism, Grandy, 1997). The trivial constructivist accepts that each individual has to construct their own knowledge of the world, but could still take the view that such knowledge is a more-or-less accurate model of the world (i.e. external objective reality), where the degree of inaccuracy can in principle be discovered and reduced. Radical constructivists, however, see all knowledge, including science, as primarily human constructions. Taken to the extreme such a view would argue that scientific knowledge is just the product of a particular culture at a particular time and place.

This is of course the relativist position: that knowledge is relative to the knower. Professional *natural* scientists would find this difficult to accept, and carry out their work as if there is an objective world that can be known through science. From such a perspective earthquakes, draughts, infectious diseases and the like are considered to reflect some underlying regularities in the world, and to force their significance upon us, despite how we may wish to construe them.

Clearly this is a simplistic position, and we should be careful not to confuse *phenomena* with our classifications and conceptualisation of them. So, for example, the class of substances which are described as 'acids' or the set of phenomena considered 'oxidation' are certainly 'culturally relative', in the sense that the accepted definitions have changed over time in response to developing theory. Nevertheless, to most scientists, concepts such as 'gold', 'electron', 'carbon dioxide' or 'noble gas' do map onto some aspects of an objective world in a highly meaningful way. In the countries where most of the key CiSE research has been carried out (in Europe and especially the UK, and in NZ and Australia), science teachers usually have a strong background in the natural sciences: although it has been suggested that in the US "many constructivists [in science education] are pure empiricists because of their ignorance of the scientific process" (Cromer, 1997, p.20).

Whilst Matthews recognises that CiSE is often of the type that von Glasersfeld calls trivial, he nevertheless warns that "constructivist epistemology is fraught with grave…educational implications" and that "constructivism leads directly to relativisms of all kinds" (Matthews, 1994, p.158). Cromer argues not only that constructivists in Science Education are relativists, but also that this is tied to an ignorance of science,

> "by devaluing scientific knowledge - bringing it down, so to speak, to the level of everyday knowledge - constructivist educators with no knowledge of science have increased their own power in science education relative [sic] to educators with scientific knowledge" (Cromer, 1997, p.11)

In a more considered argument, Scerri (2003) has criticised as confused, a version of relativism propounded by a group of educators, headed by an influential US chemistry educator and strong advocate of constructivism. As has been pointed out by a number of writers (for example, several of the contributors to Matthews, 1998) there are many versions of constructivism around, *even within CiSE*.

It is certainly possible to find statements in the literature that suggest that at least some of those working in the RP are relativists. So, Yager (1995) suggests that "…constructivists do not consider knowledge to be an objective representation of an observer-independent world. For them, knowledge refers to conceptual structures that persons consider viable" (p.38). However, it would be wrong to assume that such a fundamentally relativist perspective is common throughout CiSE. Indeed, in Gilbert and Swift's (1985) analysis, discussed above, a notion of objective reality features strongly within their proposed hard core.

There would certainly seem to be some philosophical confusion in CiSE, as Scerri (2003) has suggested. This raises the question of whether it is possible for such a range of fundamentally different viewpoints to be reflected within a single coherent RP. It is argued here that, although such positions are important and clearly colour researchers' work, they do not prevent CiSE forming a meaningful RP. As CiSE is about learning science, all those working in the RP must be constructivists *in terms of their view of how learning occurs*, and this hard core commitment is critical for identification with the programme.

Some critics seem to associate the constructivist approach, with its notion that each individual has to construct their own versions of the science (i.e. a belief about cognition), with the 'discovery learning' approach popular in earlier decades (Cromer, 1997), but in some ways such an approach is quite the opposite of the constructivist approach to science teaching (Driver, 1983). Indeed, the constructivist approach commonly sees social mediation as key to learning a version of science that matches target knowledge. So teachers guide the 'discovery' of scientific ideas by managing the construction of common knowledge in the classroom (Edwards and Mercer, 1987), providing appropriate scaffolding to shape students' constructions (Scott, 1998), and helping the learners recreate the entities of science previously constructed by professional scientists (Ogborn et al., 1996).

Perhaps one aspect of CiSE that seems to many critics to reflect a relativist stance is the attention paid to learners' ideas, e.g. Millar's (1989) suggestion that *taking learners' ideas seriously* needs to be reconciled with science as a body of consensually agreed knowledge. Learners' conceptions of science are afforded a considerable status in CiSE, but that status is related to the perceived educational significance of those ideas, and should not be considered evidence of relativism. The importance assigned to learners' ideas is due to their potential value in informing pedagogy (e.g., Leach and Scott's 2002 notion of the 'learning demand'), and is not an indication that these 'alternative scientific conceptions' are seen as a valid alternative to formal science. CiSE is primarily a programme generating knowledge aimed at improving teaching, so that science teachers can more effectively facilitate the learning of *prescribed* science. This prescribed science is the set of representations or models of science in the curriculum, which are intended to reflect the models of science itself (Gilbert, Osborne & Fensham, 1982). These curriculum models may, or may not, be considered to be authentic reflections of 'professional' science (Taber, 2003; Kind & Taber, 2005), but none-the-less provide a very definite 'target knowledge'.

The everyday experience of science teachers is that their students are assessed (and so their own teaching judged) in terms of convincing assessors and examiners that students have learnt and understand the versions of scientific knowledge represented in the curriculum. Even any committed relativists that may be working in the CiSE programme are involved in a activity/concern that is largely about helping teachers find ways to help learners 'get the science right' (albeit more so in some educational systems than others, cf. criticisms of New Zealand curriculum reforms, see Bell, Jones & Car, 1995). Whether or not scientific knowledge *should* be considered 'objective', formal education is largely based around the notion of mastering a *given* body of knowledge.

Criticism 2: CiSE uses invalid theoretical constructs

Many terms have been used to describe learners' ideas in science (intuitive physics, preconceptions, children's science, misconceptions, pre-instructional thinking, etc.) and the lack of an agreed terminology (Driver and Erickson, 1983; Gilbert and Watts, 1983; Abimbola, 1988) has certainly sometimes impeded effective communication between authors writing about this area.

Driver and Easley's seminal (1978) paper suggested the term alternative frameworks (p.62). The use of the term 'frameworks' by different researchers has been inconsistent and sometimes unclear, and attempts to clarify it have not been successful (Black and Lucas, 1993, p.xii), so, for example, the term 'conception' has often been used synonymously with 'framework' (Watts and Gilbert, 1983, pp.161; Hewson, 1985, p.154).

One further source of confusion is that references to alternative frameworks in the CiSE research reports relate to two distinct claims:

- claim 1: learners have 'alternative frameworks_1'.
- claim 2: researchers have constructed some 'alternative frameworks_2'.

The subscripts refer to two discrete meanings of the term framework:
alternative frameworks_1 are "the mental organisation imposed by an individual on sensory inputs" (Driver and Erickson, 1983, p.39), and alternative frameworks_2 are "thematic interpretations of data, stylised, mild caricatures of the responses" (Gilbert and Watts, 1983). For a worker participating in the same RP - these two knowledge claims have a very different status.

Claim 1 is a reference to one of the key aspects of the hard core of the RP: something that is protected by the negative heuristic. Workers within the RP will not find it fruitful to undertake research to falsify the claim (leaving aside arguments about the use of 'alternative framework' as the descriptor of choice), which is an essential prerequisite for the RP to proceed. Claim 1 is a claim about the tenets of CiSE.

Claim 2 concerns only the proficiency of the researcher as a competent practitioner in the field. The positive heuristic of the RP leads to enquiry into eliciting learner's ideas, and constructing representations that (a) other researchers accept as authentic, and (b) are in a form that may be readily communicated to those teaching science. Individual examples of claim 2 make up part of the protective belt of theory in the RP.

For researchers working within the CiSE, RP claim 1 is therefore axiomatic, whereas specific examples of claim 2 are peripheral. A statement that alternative frameworks$_1$ (or some alternative term for examples of children's science) do not exist is an attack on CiSE, and by definition cannot be made from within the RP. A statement that certain alternative frameworks$_2$ do not exist (i.e. do not reflect learners' thinking in a meaningful way) is merely questioning the work of the individual researcher(s), and does not necessarily have serious implications for the RP. Indeed criticisms of alternative frameworks$_2$ would be quite proper within the programme, directed by the positive heuristic (see Table 1, point 2).

There have also been criticisms of the use of terms such as alternative conceptions and frameworks (AC/F) from those who might be considered to working within (or at least at the edges of) the RP. Some references in the literature to aspects of learners' ideas in alternative terms (Andersson, 1986; Hammer, 1996; Watts & Taber, 1996) may well be describing conceptual entities that could exist alongside alternative frameworks, i.e. at a different level of organisation in the brain, and can certainly fit within the auxiliary theory of the RP.

Other alternative constructs for describing learners' ideas have been proposed because some workers feel that AC/F as proposed in the literature have characteristics that they do not feel do reflect aspects of learners' thinking. The argument here is that something labeled as a conceptual framework should be expected to be logically consistent, applicable to a wide range of phenomena, and coherently and consistently applied across their range of application (cf. Driver, 1989, p.483.) A wide range of positions have been taken by workers in the field, all supposedly based on empirical data collected from learners. In particular, there has been debate over:
1. the extent to which learners alternative ideas are stable, rather than being largely created in the context of clinical interviews, test situations or social chit-chat (e.g. Gilbert et al., 1982; Driver, 1983; Pope & Gilbert, 1983; Solomon, 1992; Claxton, 1993);
2. the extent to which children's science is theory-like, in terms of having the coherence expected of scientific explanatory frameworks (e.g. Driver & Easley, 1978; Gilbert et al., 1982; Driver et al., 1985b; Claxton, 1993)

3. the extent to which children's science comprises of ideas which are integrated together in cognitive structure, rather than being a collection of discrete conceptions (e.g. Millar, 1989; Claxton, 1993);

One area of debate has concerned the significance of learners' comments that seem to reflect 'multiple frameworks', several different alternative frameworks:

(a) whether such findings invalidate the reported alternative frameworks (Pope & Denicolo, 1986), or rather reflect the way people may indeed often hold "multiple, contradictory notions" (Ault, Novak and Gowin, 1984, p.447 cf. Bachelard, 1968 {1940}), and - if the latter –
(b) whether such manifold conceptions can still be considered as of pedagogic significance (Taber, 2000b), and offer the RP an additional perspective for studying and evaluating learning (Mortimer, 1995; Taber, 2001a).

Debates about the stability, coherence, range of application, etc. of learners' ideas are part of the proper business of the RP. Arguments over the nature of learners' ideas, as well as the validity of specific posited AC/F, are directed by the positive heuristic, and attack auxiliary theory (from within the protective belt), rather than the hard core of the RP.

Criticism 3. CiSE marginalises the social perspective

Solomon has been critical of CiSE, and has suggested that the notion of the 'pupil as scientist' (Driver, 1983) is seriously flawed. One of the outcomes of children's science interacting with formal instruction identified by Gilbert and coworkers was the 'two outcomes perspective' where pupils learn presented theories and explanations, and can use them in class and in tests, but revert to their existing ideas in everyday conversation and problem-solving (Gilbert, Osborne & Fensham, 1982, p.624). For Solomon this is largely to be expected. She has suggested that one should distinguish between what she labels 'the natural attitude' and 'symbolic universes of knowledge' (1993b).

The natural attitude is characterised as to categorise experience loosely, to typify, and to absorb knowledge into fragmented meaning structures, storing their formal school science knowledge “in a different compartment from that of the familiar life-world thought of daily discourse” (1993b, p.96). So, for Solomon, 'children's science' is less an untutored alternative to school science, than something that has persistence and social value, as - for children and most adults - it is the theories of formal science that are fragile, and have low social value.

Solomon's arguments about the nature of life-world knowledge certainly need to be taken seriously, and must be considered when investigating topics such as energy or plant nutrition which feature in everyday discourse. However, life-world thinking does not explain the many alternative conceptions in chemistry. Unless the 'life-world' knowledge system commonly includes discourse on the behaviour of atoms and electrons, it can not be invoked to explain (for example) why so many learners at upper secondary and college level adopt a common alternative conceptual framework from chemistry education when explaining chemical bonding and chemical reactions at the molecular level (Taber, 1998).

Solomon's criticisms are aimed at the notion of 'personal' (i.e. individual) construction of knowledge, as in her view knowledge construction (in science or school) is a social process, mediated by the tools of culture such as words. Any RP needs to start by abstracting out certain features for study, and the importance of social interactions were acknowledged from the start (Driver and Easley's 1978, p.76), even if attention was initially focused elsewhere. The position of Driver and her coworkers developed somewhat to take greater account of such wider perspectives (Driver et al., 1994c) Solomon's work can be seen to act as a spur to these developments, and to be closely related to the key research questions of the positive heuristic of the RP: how does knowledge construction (learning) take place? (e.g. to what extent is learning socially mediated?); how much commonality is there between learners' ideas in science (e.g. to what extent does shared culture and language lead to shared understandings?); and how should constructivist teachers teach science?

Criticism 4. CiSE does not inform teaching

Johnstone has argued that "as researchers we have solved almost none of the reported problems in chemistry teaching:…Research literature has been dominated by work on misconceptions, but little has as yet appeared about how to reverse these or to avoid them altogether" (2000, p.10). Solomon's criticism of personal (i.e. individual, cf. social) construction of knowledge as a model of learning also extends to personal construction of knowledge as a referent for planning teaching. Solomon has pointed out that for a teacher to be aware of learners' ideas is not the same as having a means of bringing about the desired changes (1994, p.10).

Yet this view ignores the way that much of the research has indeed set out to "develop revised teaching approaches which would be informed by research on children's thinking in science and current theoretical developments in cognition" (Driver and Oldham, 1986, p.105). A basic tenet of this approach was that the curriculum should be a programme of activities that encourage pupils to (re)construct scientific knowledge (p.112-116). The teacher's role was to be a "facilitator" who would provide the appropriate opportunities for the pupils to undertake the construction - including exposure to conflict situations and construction and evaluation of new ideas.

Millar (1989) is generally sympathetic to the CiSE RP, but does not feel that constructivism as a theory of learning implies a particular teaching approach. Millar's criticism that the constructivist model of learning has been (inappropriately) associated with a particular model of instruction can certainly be seen as consistent with the hard core of the CiSE RP and informed by the positive heuristic (e.g. how should constructivist teachers teach science?) Harlen (1999) has concluded that "there is no firm evidence as to the effectiveness of different approaches to developing pupils' ideas within a constructivist framework" – however, it seems fair to argue that the evidence is not (yet) available because of the relatively immature status of the field.

Criticism 5. CiSE has monopolised resources in the field

Critics of the CiSE RP would argue that the immense research effort uncovering learners' ideas in science has not been effective in informing teaching in the way that was hoped at the outset of the programme. For Johnstone (2000), the dominance of 'alternative frameworks' research has distracted attention from more fruitful approaches based upon information processing models.

By 1994 Solomon was suggesting that the CiSE programme seemed to have lost direction, and drew attention to what she suggested might be the fall of constructivism. Echoing Johnstone's viewpoint, she suggested that a popular but directionless constructivist movement could be 'damaging'. In Lakatosian terms, Solomon's suggestion was that CiSE had become a degenerating RP. According to Lakatos, a RP retains its adherents until a more promising candidate RP comes along, so the apparent reduction in interest in CiSE could be seen as a sign that this is no longer the most fruitful area of Science Education to work in. Erickson (2000) has discussed CiSE in terms of being one of several RP currently operating in the Science Education field.

Constructivism as a degenerate research programme?

The apparent drop in interest and activity in the CiSE RP could have been a sign of a degenerate RP, but this is not the only feasible interpretation. The view taken here is that it represents a welcome transition in the nature of work being undertaken in the RP.

In terms of the research questions set out in Table 1, it seems clear that much of the activity most clearly associated with CiSE concerned two of the questions: 'how much commonality is there between learners' ideas in science?', and particularly, 'what ideas do learners bring to science classes?' It might be suggested that these are the 'easiest' questions where relative small-scale research can get publishable results.

The positive heuristic directed researchers to uncover learners' ideas in science, and they responded. The information obtained is genuinely useful to teachers who are prepared to spend a little time becoming familiar with accessible summaries (Driver et al., 1994; Barker, 2000; Taber 2002), as it can sensitize them to learners' prior thinking, and to the common misunderstandings that are likely where teaching does not take learners' ideas into account. However, it is possible to consider this phase of research, if not entirely atheoretical (many of the CiSE RP papers cited here contribute theoretically, although many other published accounts were largely empirical studies framed through previously published theory), as being in a similar relation as natural history to modern biology. The cataloging of children's science might be considered the essential precursor to the development of testable ideas about how teaching can be made more effective in the light of the constructivist perspective. However, the next phase of research is more demanding both in terms of conceptualisation, and in the methods needed to obtain meaningful research results. As Lakatos warned, "One must treat budding programmes leniently: programmes may take decades before they get off the ground and become empirically progressive" (Lakatos, 1978{1973}, p.6).

Concluding comments: a progressive RP into learning science

The field of Science Education has seen an active RP into learning of science known as constructivism (in Science Education) or the Alternative Conceptions Movement. Early papers set out the tenets of the programme, and indicated some of the key concerns that needed to be explored through the research. There was no shortage of empirical progress, with vast amounts of data being collected and reported. Theoretical constructs (e.g. 'alternative frameworks') have been presented, and have been challenged. Theory has developed in response to such challenges, and the original focus has been widened in response to criticisms that key aspects of learning were being ignored (e.g. social factors of learning).

Clear messages from this body of research are somewhat obscured by the lack of agreed terminology, and the diversity of philosophical underpinnings and methodological commitments among various researchers. However, the original RP can clearly be identified in much of the diverse literature on learners' ideas in science.

The literature certainly provides advice on teaching many specific topics in the light of findings about learners' ideas: e.g. advice on where to put emphasis in teaching, on notions that commonly need to be challenged, and on the sequencing of ideas (e.g. Taber, 2001b, 2002). However, in terms of broad strategies and teaching approaches, the programme does not seem to have yet led to generally accepted evidence of effectiveness. Lakatos' offer of leniency should be accepted here.

It became clear early in the RP that 'one shot' attempts to elicit ideas from groups of learners had limited value (Gilbert and Watts, 1983; Watts, 1988; Black 1989). If the time-scale over which substantial learning could be expected to occur was indeed months and years (Driver and Erickson, 1983, p.54), then as Gilbert and Watts had suggested there was a need for "successive re-inquiries" into the frameworks used by individuals over several years (1983, p.87; cf. Bell, 1995). This has meant a change of direction for the RP. By looking at individual learners in depth, and over extended time periods, the conceptual development research programme is moving well beyond the 'butterfly collecting' stage of listing alternative conceptions.

Such studies require careful analytical approaches - such as Johnson and Gott's 'neutral ground' (1996), Petri & Niedderer's 'iterative hermeneutic interpretation procedure' (1998), or grounded theory (Taber, 2000a). Being longitudinal, such studies are slow to produce results. Nevertheless, a canon of such work is being established in the literature (Ault, Novak and Gowin, 1984; Hewson & Hennessey, 1992; Scott, 1992; Schwedes & Schmidt, 1992; Taber, 1995, 2000b, 2001a; Johnson, 1998; Petri & Niedderer, 1998; Tytler, 1998; Harrison & Treagust, 2000).

Learning is a very complex process, and so many questions raised by the RP - both at its outset, and as the protective belt of theory has developed - are unlikely to have straight-forward answers. With hind-sight, questions asking whether learners' ideas 'are' theory-like, coherent, tentative, used consistently, tenacious, applied widely, fragmentary, well-integrated, etc. are inviting diverse and confused answers. The RP needs to consider *the extent* to which (and *conditions when*) learners' ideas have these different properties, to provide teachers with theory that has more predictive power.

The protective belt of theory has led to notions (the 'refutable variants' of the research-programme) such as Pope and Denicolo's 'multiple frameworks' and Solomon's 'life-world' knowledge. There is much scope to look to bring into the RP parallel work like that of researchers such as Chi (1992, cf. Howe, 1998) who argues that research should be focused on exploring knowledge structure and coherence.

Indeed, one of the most disappointing aspects of the constructivist programme to date is the way that there have been limited attempts to link up with what would clearly seem to be related areas of work, such as the research on domain specificity, natural kinds, and so forth. Research into human memory, and problem solving, enquiry into the roles of metaphor and analogy in knowledge construction and learning, would seem to fit well into the RP discussed in this paper. Even work on conceptual change theories, and learners' mental models, has sometimes been seen as distinct from CiSE. The Lakatosian analysis, identifying the hard core of the RP, provides a sound basis for judging whether different strands of research, perhaps seeming to be based on very different fundamental assumptions – e.g. informed by 'neurocomputational' (Roth, 2000) and 'connectivist' (Fowler & Brooks, 1991) approaches - can fit within the a single RP.

This Lakatosian analysis can guide a progressive RP that is able to encompass a diverse range of studies into the learning of science: studies looking at the social mediation of science learning in the classroom and the way teachers scaffold learning processes; work focusing on the cognitive aspects of knowledge construction (such as information processing models, problem solving research); as well as studies primarily focusing on the conceptual structures pupils bring to, and develop in, their science lessons.

Perhaps the constructivist label may work against the future success of this RP. An alternative descriptor might be 'contingency'. Learning science is contingent on many factors: the available pre-requisite knowledge (and its match with accepted science); various perceptual/cognitive biases in the learner's cognitive system; the limitations of cognitive processing (e.g. working memory); features of the language of instruction; the pedagogic subject knowledge and scaffolding skills of the teacher; the social milieu in the classroom; and so much more. Exploring the nature and relative importance of these various contingencies and how they relate to aspects of the subject material to be learnt has considerable potential to inform science teaching.

The central idea of this progressive 'Contingent Learning and Science Teaching' RP is that learning of science is highly contingent: on existing learning, on the stability and coherence of existing representations, on the limitations of the cognitive apparatus (e.g. working memory), on the context and conditions of learning. Projects that seek to contribute to the RP by inquiring into these various contingencies can contribute to the next stage of a progressive programme of research into learning science.

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