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Steve Bishop and Jackie Carpenter

Process Science?

Process science has had a large impact on school science, particularly through schemes such as the Warwick Process Science Project and *Science in Process*. In this article we want to examine whether process science is valid and to examine the *Science in Process* scheme in more depth. To this end the reasons for the introduction of process science are examined and critiqued and the inductivist approach of process science will be looked at. We conclude with an evaluation of the *SiP* scheme together with a tentative model of a distinctively Christian view of the science 'process'.

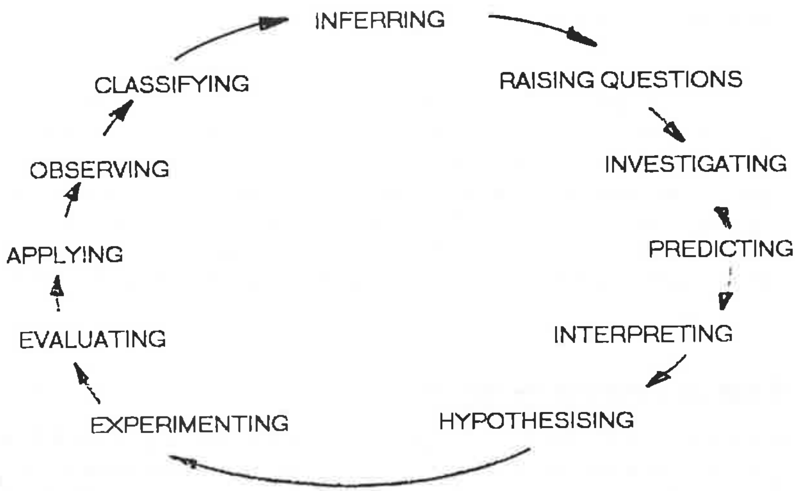
What is Process Science?

Process science as the name suggests, is science that is process led, as opposed to science that is content- or knowledge- led. It promotes a view of science that focuses on the skills or processes rather than on content or knowledge. Being a 'scientist' is seen in terms of *doing* science.

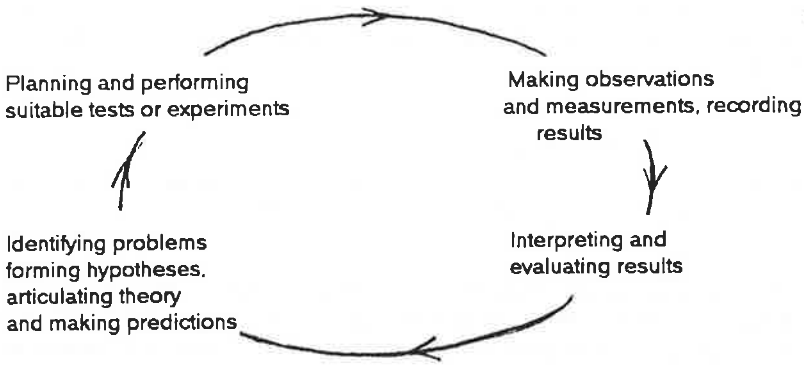
Several process science courses have been developed in recent years. These include the Warwick Process Science Project (WPSP) (1986) and ILEA's Science in Process (SiP) (1987). Each course focuses on similar, though not identical, skills. Peter Screen of Warwick University, the course director of WPSP, identifies the following processes (Screen, 1988):

There is some minor disagreement as to the nature of the processes or skills. The Leicestershire group make the point that the skills, being part of a cycle, are interdependent (p. 6). Screen has a hierarchy, beginning with observing and ending with hypothesising, although classifying and observing, which he sees as being directly dependent on the processes of observing, are parallel and level in status (1986). Although elsewhere he states that the processes: 'are cyclical, interdependent and in operation should *not* be thought of as a linear progression' (Screen, 1988, p. 146; his italics). SiP states that: 'The process-skills are not presented with any predefined notion of sequence' (p. 12).

SiP selects the following:



Leicestershire's *Science as a Process* (1985) narrowed the skills down to four main areas:



Why Process Science?

Screen justifies the advent of the WPSP by the following points.

1. 'The explosion of knowledge has . . . contributed to making the teaching of facts questionable' (p. 13). He points to the growth of the Proceedings of the National Academy of Sciences as evidence. In 1953

they measured 5 cm, in 1963 10 cm, in 1973 18 cm and in 1983 37 cm; almost doubling in size every 10 years! This then leads to his second justification.

2. 'What should be required of science education is the ability to access, use, and ultimately add to the information store when required' (p. 13); skills rather than knowledge are more relevant to pupils in this 'information age'.

3. 'The most valuable elements of a scientific education are those that remain after the facts have been forgotten' (1986, p. 13).

4. It is found to be appropriate for mixed ability ranges (1986, p. 15): 'there is an inbuilt opportunity for all students to succeed' (1988, p. 149) . . . 'success is built on success, whereas in a knowledge-based course where facts have to be learned and reproduced as a means of attainment, failure is implicit' (1986, p. 16).

5. It re-establishes something of the integrity of science (Screen, 1988, p. 149). Students are not asked to come to conclusions—there is therefore no temptation to 'cook the results': 'Asking students to infer from their observations enables them to show integrity and at the same time broadens the possibilities so that the creative aspects of science can be developed' (1988, p. 149).

6. Through process science a teacher can evaluate and therefore challenge the students' misconceptions: 'processes reveal what students have internalised about an idea and not what they can regurgitate as facts' (1988, p. 149).

Why Not Process Science?

These six reasons present a *prima facie* case for adopting a process science course; however, on closer examination there are serious problems with each. We will deal with each of them in turn.

1. The Explosion of Knowledge

There is no doubting the explosion of the availability or accessibility of knowledge, the increasing number of books and monographs published and the growth of old and the launch of new academic journals is testimony to that. (Although the launch of new journals is often driven by economics rather than a desire to serve the scientific community.) To see education in terms of processing information is inevitably reductionistic; the human brain is not merely an information processor. Knowledge is not the same as the ability to process information (Wellington, 1988, p. 151–2).

2. *Skills are More Relevant*

This is an unashamedly pragmatic view of science; a view that, incidentally, is reflected in the National Curriculum (Roques, 1989, p. 241). Surely, science education is more than equipping pupils for the 'information age's' job market. It also fails to do justice to the nature of science.

3. *The Transitory Nature of Scientific Knowledge*

Jerry Wellington identifies three false assumptions that underlie this assertion: i.e. scientific knowledge soon dates, scientific skills are not provisional in nature and skills are more readily retained than knowledge.

(i) Scientific knowledge soon dates. This is certainly not true of science in schools. Almost all of school science is a body of knowledge agreed by the scientific community. Emphases may change, for example the advent of topics such as acid rain and the greenhouse effect, and the recent scientific 'advances' such as high-temperature superconductivity and cold fusion, may have to be incorporated but almost all the school science taught fifty years ago would still be valid today. Even Newtonian mechanics still holds sway up to sixth form level!

(ii) Scientific skills are not provisional in nature. The history of science is littered with discarded methods of science: induction, deduction, hypothetico-deductivism and Feyerabend's anarchistic 'anything goes' approach. Scientific skills then are anything but non-provisional.

(iii) Skills and processes are more readily retained than knowledge. There is no evidence to show that this is so. Millar even goes as far as to suggest that 'there is no evidence that we improve our performance of any of these processes' (Millar, 1988, p. 156). A damning indictment! The attempt to teach process skills is described by Millar as the 'pursuit of the impossible'. These 'process skills' are 'general cognitive skills which all humans routinely employ from birth, without formal instruction, so that it is absurd to claim that these can (or need) in any sense be *taught* or *developed* (Millar, 1991).

4. *Appropriate for Mixed Ability Groups*

There is no evidence that processes are more accessible to lower-ability pupils than 'facts' (Wellington, 1988, p. 151; Millar, 1988, p. 158). But even if it were true, it would provide no justification for the acceptance of a process course. An end—however laudable—does not justify the means. Pragmatism should not be the prime shaper of the curriculum.

5. Inference = Integrity?

The debate between the inference and conclusion is surely one of semantics. What are the bottom set of year 9 to make of the subtle difference between these two words? Accepting inferences rather than conclusions does not mean we have to adopt a process approach, anyway!

One thing is certain, process science does not treat the philosophy of science with integrity: it equates process science with *the method* of science. As Millar correctly states: 'it is superficial and misleading to portray the method of science in process terms' (1988, p. 156). If the history of the philosophy of science teaches us anything it is that there is no universally agreed scientific method; let alone one that is equivalent to a process model.

Much process science is 'essentially an *inductive* view' of science (Millar in Wellington [1989, p. 49]). Inductivism is the name given to the scientific method that moves from a series of observations to a hypothesis; from the specific (this piece of ice melts at 0°C) to the general (all ice melts at 0°C). This view of science has long been discarded by philosophers of science (Hodson, 1986, p. 216); Wellington (1981) comments: '. . . this view of the scientist as a Sherlock Holmes in a white coat has not been held by any philosopher of science since Francis Bacon (1561–1626)'. Despite this fact 'many teachers subscribe to an inductivist view of science' (Hodson, 1986, p. 216). It was David Hume who showed that inductivism was illogical. We cannot arrive at universals (all) from particulars (some), because we can never know how many particulars make up a universal.

The death blow to inductivism is the recognition that observation is not neutral. Observation is theory-dependent; it is therefore impossible to be a neutral observer. What we 'see' will depend on what we know and what we expect to see. Any number of optical illusions illustrate this point.

Hodson remarks, 'Observation would appear to be more than merely seeing and seeing would appear to be more than simply receiving sense data. Something is added at each state' (1986, p. 22). The following diagram summarises Hodson's points (Hodson, 1986).

If observation is theory-dependent, then it follows that observation will be influenced by any pre-existing theory: sugar in a liquid *dissolves*; we no longer see it disappear (Hodson, 1986, p. 218).

6. Revelation of Internalised Ideas

It is not clear how process science reveals internalised ideas. This argument for process science is probably an attempt to jump on the constructivist bandwagon (see Bishop and Carpenter, 1993 for a discussion of constructivism). If we want to identify pupil's misconceptions or 'internalised ideas' there are much better techniques than process science; for example: concept mapping and interview-about-instances techniques.

Semantic Confusion

What does process science mean by the term 'process'? The term was first used in the context of science education in the 1960s by Gagne. Gagne argued that processes like observing and classifying are skills used by all scientists and that they can be applicable to investigation in all the sciences, that they can be learnt by students and be transferred across context domains. However, Millar and Driver (1987) suggest that there are a number of different meanings for the term process, and each has its own problems. The different meanings given to the word process, identified by Millar and Driver, are:

> the processes scientists use in investigating the natural world; the cognitive processes involved in learning science and the pedagogical processes taking place in classrooms

The first meaning, the processes scientists use, has problems, since the simple inductivist method is not used by scientists, and thus gives a false impression to the pupils of science.

The empirical processes that start with observation and lead through experimentation do not model children's learning. What children notice, do and the interpretations they give depends on prior knowledge and understanding. Hence, the second meaning of 'process' is not without its problems.

If they are pedagogical processes, then this too is problematical. Process science rests on the assumption that certain context-independent processes can be taught and applied by learners in fresh situations (Millar and Driver, 1987, p. 51). How can we teach children to observe when observation is theory-laden?; how can we teach children to classify when classification is also theory-laden? Millar provides a good example of the latter (Millar, 1991, p. 49):

> A whale is classified along with the mammals and not as a fish, not because this is obviously so, nor because it is necessarily entailed by 'the way the world is'. Rather it is a decision to give greater weight to the criterion 'bears and suckles live young' than to the criterion 'lives in the sea'. This decision, in

turn, is based on wider theories which scientists hold about the origin and evolution of species.

Dewey Rides Again

Philosophically, process science's roots can be traced back to the American pragmatist John Dewey (1859–1952).

The influence of Dewey on twentieth century thought is evidenced by the fact that he is the only living philosopher to have a chapter devoted to him in Bertrand Russell's *A History of Western Philosophy*. Russell has this to say of him:

> John Dewey, who was born in 1859, is generally admitted to be the leading living philosopher of America. In this estimate I entirely concur. He has a profound influence, not only among philosophers, but on students of education, aesthetics, and political theory. He is a man of the highest character, liberal in outlook, generous and kind in personal relations, indefatigable in work. With many of his opinions I am in almost complete agreement (Russell, 1979 [orig. 1946] p. 774).

Dewey was one of the chief proponents of the philosophical school that became known as pragmatism. The other leading lights were C.S. Pierce (1839–1914) and William James (1842–1910). Pierce developed a pragmatic theory of meaning, James a pragmatic theory of truth; it was Dewey who modified these approaches and applied them to social and political philosophy (Morgenbesser, 1987).

For Dewey truth is an instrument used by humans to solve their problems; consequently it must change as their problems change, it is constantly evolving. It is the *process* rather than the *product* that is all important. It is for this instrumentalist view of truth that Dewey is best-known. Truth is a tool, it is usefulness. Truth is a process: it is the search for truth not truth that sets us free. It is these ideas that lie, tacitly, behind process science.

Dewey based his view of education on the basis of reflective inquiry and of testing by action. He was influenced by positivism, and for him reality can only consist of what can be experienced. Common human experience is the only basis for knowing reality and whatever lies beyond the world of ordinary human experience is unknowable. This is obviously at odds with a Christian epistemology and ontology: knowledge cannot be reduced to experience; and we cannot sever epistemology and ontology (see Bishop and Carpenter, 1993).

Magee (1987) comments that for Dewey:

> We are living organisms in an environment in which, above all else, our concern is to survive; and one of the most important survival mechanisms we have—perhaps *the* most important—is knowledge, because it confers

> understanding of the environment and, through that, a degree of mastery of it. . . . The would-be knower is a biological organism struggling for survival —not a spectator but an agent.

This approach overemphasises the biological aspect of knowledge and consequently idolises it. From a Christian perspective humans are much more than biological organisms struggling for survival!

Nevertheless, Dewey has had some important insights for education. The whole emphasis on inquiry-based approaches, such as process science, is a result of Dewey's work. Knowledge, in part, does demand the participation of the student in the learning process; it should not however, be allowed to dominate it as it does in Dewey and process science.

Criteria for a Christian Science Course

What makes a science course Christian? We want to suggest the following aspects, in no particular order, will be included in a Christian science course. The list is provisional and reflects our current thinking.[1] (It is also presented without justification; to do so would require a separate article, as we are well aware that some of the criteria are contentious among Christians.) Many of the items in the list will also be shared by those of other worldviews.

1. It will be anti-racist.
2. It will be anti-sexist.
3. It will provide a sense of awe and thus contribute to a worship of God rather than a particular scientific method.
4. It will be holistic and a top-down approach, rejecting a reductionistic (bottom up) materialist approach.
5. It will enable pupils to understand the role of things (e.g. air, water, plants, soil, rock, animals and humans) in creation.
6. It will show that the creation is a consistent and ordered place, faithful to God's law.
7. It will express the diversity within unity of the creation.
8. It will enable pupils to make sense of God's world.
9. It will promote the role of humans as responsible stewards of God's creation.
10. It will see God as the source of all things; hence it will undermine the idea that science is autonomous.

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1. Some of these ideas have been developed in conjunction with the Christian Schools Science Curriculum Working Group. See for example the *Introductory Statement* available from the SCWG c/o Oak Hill School, 16 Cotham Park, Cotham, Bristol, BS6 6BU.

11. It will promote the idea that science is a tool for the unfolding and developing of creation.
12. It will see science as an aspect, and only one aspect of God's creation; thereby it will not denigrate the role of other subjects in the curriculum; neither will it condone the scientistic idea that science explains the whole of reality.
13. It will expose the myth of the neutrality of science.
14. It will show that scientific activity is laden with the values of the worldview of the scientist.
15. It will undermine scientism: the idea that science is the only way of knowing and that science given enough time and money can solve all our problems.

Using these criteria we can see how compatible with a Christian approach to science one process science course, SiP, is.

Science in Process: A Critique

This critique is based on the suggested criteria for a Christian science course.

Science in Process makes a bold attempt to address the first two criteria on our list. It does go some way to address gender stereotyping and racism. Throughout the book there is a good mix of both male *and* female pupils of European, African and Asian origin engaged in scientific activities. However, like most textbooks, it fails to provide much information about coloured or women scientists. There is nothing, for example, about the many scientific discoveries made in early China. (The Chinese at one stage in their history, when Europe was going through the Dark Ages, led the world in science and technological innovation (Needham, 1969)—even though scientific development there was still born.) Though it does show an ancient black Egyptian throwing an early boomerang, a female Chinese medical worker and Madame Lavoiser makes a brief appearance in a cartoon, to take but three examples.

It falls short of all the other criteria. This is not surprising, because firstly it was not written with them in mind and secondly, it is not designed as a Christian course. Consequently, it does not promote a sense of awe in God or his creation, it does not portray God as the source and sustainer of all things.

The course promotes a completely different worldview to that of the Christian. The scientific method almost becomes deified. The scientific method is seen as an end in itself; there is in no sense the idea that science is merely one aspect of creation. The whole purpose of SiP is to unfold the scientific method, all else is subservient to that. The tacit message is that the scientific method is a fail safe way of understanding the world and solving all the problems we are confronted by. This is scientism.

In pursuit of its aim to teach a scientific method it fails to do justice to God's creation. In the topic book on Air[2] (p. 2.2) we find a 'spread' on birds, its sole purpose is to teach observation and classification skills using wing shapes. The role of birds in creation is ignored (criterion 5).

SiP does make some attempt to investigate the 'real world'; many of the scientific investigations use everyday items such as: lemonade, honey, salt, sand, fabric dyes, red cabbage (to take some examples from Theme 3 chemicals). In Theme 10 Structure and Forces many everyday examples are examined: bridges, concrete, bags of shopping, statues, car tyres, glues . . .; every attempt has been made to make it relevant, and in this it has largely succeeded. However, is the real world of science portrayed? We have already commented that SiP abstracts out one aspect of science—a *perceived* scientific method—and makes a god out of it. All science, for SiP, is to be understood through an idealised ahistorical process. A process that bears no relationship to the history of science; despite its own claim to be 'aware of [science's] historical, cultural, and social context'.

SiP by focussing on 'processes' does violence to the diversity within unity of the created reality. The processes it attempts to teach are not specifically scientific.

The DES's *Geography from 5 to 16* (Curriculum Matters, 1986) lists several skills which should be developed in geography; these include observing and measuring; interpreting and analysing (identifying, discriminating, comparing, classifying, recognising patterns and associations, making valid generalisations from evidence); selecting, presenting and communicating information and ideas in a variety of ways (p. 29–30).

Likewise, in history we can see an almost identical set of skills being taught. In the HMI's *History in the Primary and Secondary Years* (HMSO, 1985) the following skills are listed: the ability to locate information; the ability to observe, listen and record; the ability to communicate; skills of translation (e.g. putting into written form information contained in graphs, statistics and pictures); skills of analysis and synthesis, i.e. the ability to select and organise information,

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2. There are 10 'themes' in the original SiP course. These are: 1 Be scientific; 2 Air; 3 Chemicals; 4 Communication; 5 Time; 6 Energy; 7 Environment; 8 Growing; 9 Liquids; 10 Structure and forces. They are intended to cover the first two years of a secondary science course. Two further themes and a self-contained book *Science Kaleidoscope* (London: Heinemann, 1990) were introduced in an attempt to bring it into line with the Welsh and English Science National Curriculum Key stage 3.

pose and test hypotheses, ask appropriate questions, construct narratives, write notes and essays; the ability to recall information.

If in history, geography and science we are teaching the same and similar skills and processes what messages does it give to our pupils? They will see the unity of subjects, but how can we expect them to appreciate the diversity of creation?

They will have little appreciation of the distinctiveness of science or history; by teaching the same things, i.e. processes, we blur the subject boundaries and thus violate the diversity within unity of creation.

A Critique Based on SiP's Own Aims

SiP has the stated aim to teach the pupils to become scientific rather than to learn about science; this is a very important distinction. The former assumes a child-centred approach, where the content taught is secondary. The process skills tend to become an end in themselves and the content exists merely to serve the skills. Consequently, there is little meaningful organisation of the content, so it becomes confusing and difficult to teach.

Making the pupils aware of science in its historical cultural and social context is a laudable aim, but there is very little of this in the course. It fails to deliver one of its own aims.

An Example—Theme 2: Air

This section of the course contains some interesting and enjoyable experiments. They involve plenty of group work, discussion and planning. There is plenty to do and experience. However, most pupils would have little understanding about air at the end of this topic, if the SiP course were not supplemented with other material.

A closer examination reveals further short comings. The booklet, as for all the SiP booklets, consists of double page 'spreads' which can be worked through in any order, indicative that content is subservient to the processes.

For air pressure, a 'cut out' sheet is used; here explanations are matched to observations. Unfortunately, no real understanding of air pressure is required to do the task successfully. Some work on weather is included but the link with air pressure is not made, thus producing little understanding of weather.

A spread on birds has some confused teaching aims. There is very little content about birds beyond primary school level. It is only included to teach observation, as we mentioned above. The section on fire alarms is enjoyable, but its relevance to air is not obvious! It assumes a knowledge of simple circuits, something which not all pupils will have acquired at this stage. Much better is the spread on gases in air, it is relevant to pupils and a good use of materials. Ideas about burning, the next spread, is conceptually very difficult; there is a large amount of information that is not followed up at all. A good juncture at which to discuss cultural and moral aspects of science is missed on the spread on sulphur dioxide. One spread deals with the reasons we need air, potentially an interesting and certainly vitally important topic, however it is far too cursory and out of context. The graph work is difficult for many pupils at this level.

Concluding Remarks

The inductivist philosophy that permeates process science does not provide a secure basis for a school science course. In short, process science provides a shaky foundation for a distinctively Christian science course. This does not mean we should dismiss out of hand process science; to do so would set up a dualism of content and process. Both extremes are reductionistic. A Christian view of scientific knowledge should include both—and more; for example: the consensus of the scientific knowledge, the scientist's psychology and worldview, and the historical-cultural context (see figure 1). To focus on one to the exclusion of others is to indulge in idolatry.

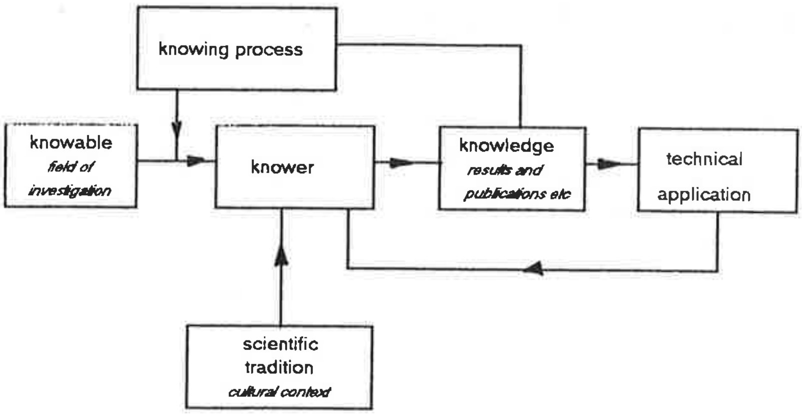

Figure 1. A schematic representation of a model of scientific investigation. Illustrating the role of both content and process among other aspects. (Source: Revd Richard Russell.)

There are many aspects of process science in general, and SiP in particular, we can affirm; SiP's anti-racist and anti-sexist stance is one.

It has also moved us away from an academic content-based science, that did more to equip people for Trivial Pursuit games than the Real world.

The process approach confuses the means with the ends. The means (processes) become the end. Processes are important, but they are not all-important, they are only one part of the whole as figure 1 shows.

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