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Constructivism: An Introduction and Critique

How do children learn? This is perhaps the most important question that confronts educationalists. How we answer it has immediate impact on what we do in the classroom.

One learning theory that has become prominent in recent years is constructivism.[1] Constructivism has been a powerful movement for change in science education particularly. One recent scheme published to meet the National Curriculum in Science, the *Oxford Science Programme*[2] has adopted a constructivist view of learning and several constructivist teaching schemes are available from the Centre for Studies in Science and Mathematics Education at Leeds University.[3] Constructivism has had increasing influence without, it seems, much searching criticism.[4] It has been described as the 'most exciting idea of the past 50 years' and as a means of 'connecting all current lines of research prevalent in science education'.[5] The purpose of this article is to examine the ideas that lie behind constructivism and to examine the role it might play in a distinctively Christian approach to science education.

Constructivism: An Introduction

A rejection of the transfer view of learning

Constructivism takes as its starting point the idea that pupils are active learners who come to science lessons with certain preconceptions of how the world is structured and ordered. It stands in direct opposition to the 'transfer view of learning'. It rejects the notion that learning is filling empty buckets and that it depends solely on the external learning situation; i.e. the teacher, classroom, books or experiments. For a constructivist, learning involves modifying or changing existing concepts

1. One major bibliography of constructivist works related to science contains over 1000 references dated from 1978–89: *Research on Student's Conceptions in Science* (CLIS, 1990).
2. Paul Denley and Stephen Pople (editors) (OUP, 1990–92).
3. At present units on Energy, The Particulate Theory of Matter, and Plant Nutrition are available.
4. One notable exception is: Robin Millar, 'Constructive criticism', *Int. J. Sci. Educ.*, vol. 11 (1989) (Special Issue), pp. 587–96.
5. Cited in Robert E. Yager, 'The constructivist learning model', *The Science Teacher*, September 1991, p. 53.

Table 1. A summary of the contrasts between a transfer view of learning and a constructivist view.[6]

	TRANSFER VIEW	CONSTRUCTIVIST VIEW
Teacher	Transmitter of knowledge	Facilitator Provider of experience
Pupil	Absorber of knowledge	Active in constructing meaning
Pupil's mind	Empty bucket	Contains strongly held preconceptions
Knowledge	Independent of knower	Constructed by each individual

that a pupil holds, and it depends on the learning situation *and* the prior knowledge/experience of the pupil. Table 1 further summarises the differences.

Constructivism then takes seriously Ausubel's statement that:

> 'If I had to reduce all of educational psychology to just one principle I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly'.

Defining constructivism

We have seen how constructivism compares with the transfer view of learning but not yet defined it. According to Mahoney:

> 'Constructivism refers to the family of theories that share the assertion that human knowledge and experience entail the (pro)active participation of the individual'.[7]

Rosalind Driver, of Leeds University and director of the Children's Learning in Science Research Group (CLIS), notes that:

> 'The perspective . . . whereby individuals through their own mental activity, experience with the environment and social interactions progressively build

6. Adapted from CLISP, *Approaches to the Particulate Theory of Matter*, (CLIS, 1987), p. 9.
7. Cited in M. Watts and M. Pope, 'Thinking about thinking, learning about learning: Constructivism in physics education', *Phys. Educ.*, vol. 24 (1989), pp. 326–31.

up and restructure their own schemes of the world around them, has been broadly termed as *constructivism*'.[8]

A brochure introducing CLIS makes the following observations:

'The CLIS Research Group holds a constructivist view of teaching and learning, seeing children's conceptions of natural phenomena as examples of the mental models which human beings are continually constructing, and which are used to anticipate and make sense of events'.

And according to Grayson H. Wheatley there are two main principles which form the foundation of constructivism:

'Principle one states that knowledge is not passively received, but is actively built up by the cognizing subject. . . . Principle two states that the function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality'.[9]

The first principle, as Wheatley rightly states, is readily agreed by most and can be empirically verified. The second is more problematic: it is the product of a faith commitment. Not all who would call themselves constructivists would hold with the assertion, thus indicating that constructivism is a broad church.

Constructivism is a term that includes a number of theories and theorists. George Kelly's personal construct theory is particularly influential, especially among scientists, perhaps because Kelly takes 'man-the-scientist' as his 'root metaphor'.[10]

Kelly writes:

'. . .when we speak of *man-the-scientist* we are speaking of all mankind not merely a particular class of men who have publically attained the stature of "scientist".'[11]

Driver's debt to Kelly is obvious from the title of her book (despite the ambiguous question mark): *The Pupil as Scientist?*.[12] Driver is an unashamed constructivist. In an article she expounds a constructivist view of science and the learning process: science 'is about the ideas, concepts and theories used to interpret the world'. It is a human construction:

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8. Driver, 'The construction of scientific knowledge' in R. Millar (ed), *Doing Science: Images of Science in Science Education*, (Falmer, 1989) p. 85.
9. Grayson H. Wheatley, 'Constructivist perspectives on science and mathematics learning', *Sci. Educ.*, vol. 75 (1) (1991), p. 10.
10. Watts and Pope, 1989, p. 327.
11. Cited in M. Pope and M. Watts, 'Constructivist goggles: implications for process in teaching and learning physics', *Eur. J. Phys.*, vol. 9 (1988), p. 103.
12. Open University, 1983.

> '. . .electrons, electric fields etc. are not part of our sense impressions, they are not even abstracted from this world. They are *imaginative constructions*, themselves related in very precise ways, which are brought to bear on this world'.[13]

Here science is a product of reason—'imaginative constructions'. Constructivism is a relativistic philosophy: we all construct our own meaning of reality; and scientific models are not based on absolute truth. This in a nutshell is Kelly's 'constructive alternativism'. Pope and Watts, self-confessed pro-constructivists,[14] comment:

> "Constructive alternativism' suggests that people understand themselves and their surroundings and anticipate future eventualities by constructing tentative models. They then evaluate these against personal criteria, so as to successfully predict and control events based upon the models. It is a philosophy that rejects an absolutist view of truth. . . . For Kelly, all theories are hypotheses created by people, which may fit all the known facts at any particular time but may eventually be found wanting in some unforeseeable respect and be replaced by a "better theory".'[15]

We can summarise constructivism in the following propositions:[16]

1. Learners are not passive.
2. Learning is a continuous and active process.
3. Knowledge is a human construction.
4. Learning is not merely the absorption of information; pupils are not sponges soaking up information.
5. Learning is not merely adding to existing concepts but may involve conceptual change.

Creating the climate for constructivism

Constructivism is not a new idea, Osbourne and Wittrock state that its origins date back to the Greeks,[17] although von Glaserfeld has traced its roots back to the Neapolitan philosopher Giambattista Vico (circa 1710).[18] Some have claimed that the early Piaget was a constructivist. Its

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13. R. Driver and B. Bell, 'Students' thinking and the learning of science: a constructivist approach', *Sch. Sci. Rev.*, vol. 67 (1986) (no. 240), p. 444; my emphasis.
14. Watts and Pope, (1989), p. 326.
15. Pope and Watts, (1988), p. 102.
16. Cf. Driver and Bell, (1986), pp. 443–56.
17. R.J. Osbourne and M.C. Wittrock, 'The generative learning model and its implications for school science', *Stud. Sci. Educ.*, vol. 12 (1985), pp. 59–87.
18. G. Vico, *De antiauissima Italorum saDientia*, (Stamperia de' Classici Latini, 1710) cited in: E. von Glasersfeld, 'Environment and communication', paper presented at the ICME-6, Budapest, Hungary. Both the above are cited in Robert E. Yager, 'The constructivist learning model', *The Science Teacher*, (Sept. 1991), p. 54.

advent in the form of Kelly's personal construct theory follows the shift from realism to relativism.[19] Empirical-inductivism which held sway 'between the two Elizabeths'[20] advocated a realist view of science; i.e. scientific theories are a true description of an objective reality. Its demise in the late 1940s—as a result of, among other things, the recognition of the theory-laden view of observation—was closely followed in succession by a number of differing views which could loosely be described as relativist. These 'relativists' (e.g. Kuhn and Feyerabend)—among many other disagreements—affirmed the following:[21]

* The provisional nature of knowledge (hence the term relativist);
* The idea that observation is theory-laden;
* An evolutionary approach to theory building; and (perhaps most significantly of all)
* A disagreement over the nature of, or even the existence of (Feyerabend), a scientific method.

It was this relativism that provided the right environment for the acceptance of Kelly's relativistic personal construct theory.[22]

Constructive teaching

The first step in constructivism is the 'elicitation of student ideas'.[23] This can be done in a variety of ways.

(a) *Interview-about-instances.* Pupils are presented with a series of cards with sample line diagrams drawn on them which may, or may not, depict examples of a certain concept. Pupils are then asked simple questions, such as, 'Is there a force here?' Reasons for their responses are then sought.[24]

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19. A brief but valuable overview and critique of the philosophy of science from a distinctly Christian perspective is: Richard Russell, *Science, Philosophy of Science and Science Education*, (CSU, no date); available from CSU, Widcombe Vicarage, 65 Prior Park Rd, Bath BA2 4NL. Another good readable introduction is Del Ratzsch, *Philosophy of Science: The Natural Sciences in Christian Perspective*, (IVP, 1986).

Also worth reading, though not specifically Christian, is A.F. Chalmers, *What is This Thing Called Science?*, (Open Univ., 1982; 2nd edn). See also Derek Hodson, 'Philosophy of science and science education', *J. Phil. Educ.*, vol. 20 (1986), pp. 215–22.

20. J.K. Gilbert and D.M. Watts, 'Concepts, misconceptions and alternative conceptions: changing perspectives in science education', *Stud. Sci. Educ.*, vol. 10 (1983), p. 62.

21. See Gilbert and Watts (1983).

22. Cf. Pope and Watts (1988) p. 102.

23. Richard Needham, *Teaching Strategies for Developing Understanding in Science*, (CLIS, 1987).

24. See, e.g., J.K. Gilbert et al., 'Elicitating student views using an interview-about-instances technique' in L.T. West and A.L. Pines (ed.), *Cognitive Structure and Conceptual Change*, (Academic, 1985).

(b) *Concept mapping.* Concept mapping is a powerful means of assessment; it is a technique for 'externalizing concepts and propositions'.[25] From a list of concepts pupils are asked to identify the relationships between them by drawing a 'map' linking each of the concepts. By examining these maps misconceptions as well as gaps in learning can readily be identified.

We have also used concept maps as teaching aids. They can also be constructed by pupils from a reading or textbook as a means of note taking. Novak and Gowin's book provides an excellent introduction to concept mapping. It also contains strategies to introduce them into primary and secondary classrooms.

(c) *Classifying statements.* Students are asked to write several sentences about a concept, then in small groups (no more than about five) the statements are pooled and classified into three groups: Agree, Disagree and Unsure. An alternative method is to present pupils with a series of statements for them to classify.

Other methods for ascertaining what the pupils know are multiple-choice questions,[26] discussion, poster making, etc.

Much research has been done on children's 'frameworks of understanding' or what has been termed 'alternative conceptions'.[27] A recently published bibliography lists over a thousand references of 'alternative conceptions research'.[28] It is apparent that many pupils hold to similar 'alternative conceptions'.[29] For instance the following have been noted in several studies regarding electricity:[30]

* current is 'used up' as it flows through a bulb;
* a change in a circuit has an effect only 'downstream' of it but not 'upstream';
* the concepts of current, voltage, energy and power are insufficiently discriminated; and
* the larger the resistance of a piece of apparatus the more energy is used up in it.

These 'alternative conceptions' are highly resistant to change even

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25. Joseph D. Novak and D. Bob Gowin, *Learning How to Learn*, (CUP, 1984), p. 17.
26. For an example see Appendix D in Roger Osbourne and Peter Freyberg, *Children's Learning in Science*, (Heinemann, 1985).
27. R. Driver and J.A. Easley, 'Pupil's paradigms—a review of literature related to concept development in adolescent science students', *Stud. Sci. Educ.* vol. 5 (1978), pp. 61–84.
28. R. Driver and D.M. Watts, *Research on students' Conceptions in Science: a Bibliography*, (CLIS, 1990).
29. If anyone is in doubt, use the multiple-choice test in Osbourne and Freyberg (1985) appendix D; you will be surprised!
30. See, e.g., David Shipstone, 'Pupil's understanding of simple electric circuits: some implications for instruction', *Phys. Educ.*, vol. 23 (1988), pp. 92–6; 'Electricity in simple circuits' in Driver et al., (1985), pp. 33–57; and the many references therein.

after traditional teaching. Hence, the next step is to 'restructure ideas'. Here the students are confronted by experiments, information or evidence that contradicts their non-scientific conceptions. It is then hoped that their conceptions will be modified to become more 'scientific'. An application stage may take place next. Here the pupils perform tasks such as discussion, further experimental work, creative writing . . . etc. that aid further restructuring of ideas.

The final stage is a review of the change in ideas. Students then are asked to reflect on how their ideas have changed, often by examining their original ideas. Pupils are thus made aware that learning involves changing their previously held concepts.

Constructivism: Towards a Critique

Worldview questions

We can begin a tentative critique of constructivism by examining the view of the world it portrays. All worldviews—even atheistic materialism—rest on faith.[31] They can all be pared back to ultimate questions, questions whose answers are the product of faith. These ultimate questions include the following:

1. What is reality?
2. How do we know?
3. What does it mean to be human?
4. What is wrong?
5. What is the remedy?[32]

How would a full-blooded constructivist answer these questions? To some extent, these questions have been answered in the foregoing; though it will be worth making the answers explicit.

What is reality? Kelly's 'individuality corollary' answers this question concisely: 'People differ from each other in their construction of events'.[33]

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31. For an excellent analysis of this assertion see Roy A. Clouser, *The Myth of Religious Neutrality: An Essay on the Hidden Role of Religious Beliefs in Theories*, (University of Notre Dame Press, 1991).
32. It may appear simplistic to reduce world views to such questions; but yet these questions contain deep philosophical implications about ontology, epistemology and anthropology. For a justification of such an approach see, for example, Brian J. Walsh and J. Richard Middleton, *The Transforming Vision*, (IVP, 1984). A similar approach is used in Leslie Stevenson, *Seven Theories of Human Nature*, (Oxford University Press, 1974); cf. also James Sire, *The Universe Next Door*, (IVP, 1976). N.T. Wright has also shown the fruitfulness of this approach in theology; see *The New Testament and the People of God*, (Christian Origins and the Question of God: vol. 1) (SPCK, 1992).
33. Cited in Pope and Watts, (1988), p. 103.

Reality is relative and subjective; one person's view of reality will differ from another's. We construct our own reality. According to von Glaserfeld: 'Facts are made by us and our way of experiencing'. Gone is any idea of a God-given order to creation. Viability replaces truth:

> 'The revolutionary aspect of constructivism lies in the assertion that knowledge cannot and need not be "true" in the sense that it matches ontological reality, it only has to be "viable" in the sense that it fits within the experiential constraints that limit the cognizing organism's possibilities of acting and thinking'.[34]

It is the construction of 'viable explanations of our experience' rather than the truth that will set us free! Truth cannot be reduced to viability.

How do we know? The tendency with some constructivists is to divorce epistemology (the theory of knowledge) from ontology (the theory of reality):

> '. . .knowledge can be seen to be valid if it is useful in interpreting experience. There is thus no ultimate check that a particular construction is 'right' insofar as it is isomorphic with an externally existing reality'.[35]

Knowledge is not a representation of what exists. Constructivism takes a pragmatic view of knowledge: something is 'true' if it works:

> '. . .knowledge originates in the learner's activity performed on objects'.[36]

This is a distorted view of knowledge. Knowledge does not have its origin in anything created, whether it be in our brains, activities or objects. Its source and origin must ultimately be Jesus, who is the source and sustainer of all things (cf. Col 1:16–17). Knowledge has at least three dimensions: the knower, the knowing and the knowable.[37]

The process of knowing is fallible and personal, there is an 'epistemological subjectivity'; but what is knowable is rooted in universal truth, there is a 'metaphysical objectivity'.[39] Constructivists, such as Wheatley and von Glaserfeld acknowledge the former, but deny the latter. The knowable, however, cannot be separated from the way

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34. E. von Glaserfeld, *Constructivism as a Scientific Method*, (Pergamon, 1987) cited in Grayston H. Wheatley, 'Constructivist perspectives on science and mathematics learning', *Sci. Educ.*, vol. 75 (1991), p. 10.
35. R. Driver, 'Changing conceptions' in *Adolescent Development and School Science*, (ed. P. Adey *et al.*), (Falmer, 1989), p. 81.
36. Wheatley p. 10.
37. See, for example, Doug Blomberg 'Toward a Christian theory of knowledge' in *No Icing on the Cake: Christian Foundations for Education*, (ed. Jack Mechcielsen), (Brookes-Hall Publishing Foundation, 1980).
38. This thesis is defended by Arthur Holmes, *All Truth is God's Truth*, (IVP, 1979; UK edn); the terms epistemological subjectivity and metaphysical objectivity are his. Cf. also Michael Polanyi, who argues that knowledge is both objective and personal.

things are, as such constructivists attempt to do, without distorting and reducing knowledge.

> '. . .a constructivist believes that knowledge is not disembodied but is intimately related to the action and experience of a learner—it is always contextual and never separated from the knower'.[39]

This is true as far as it goes, but it is not the whole picture, it is a reductionistic explanation. Ultimately it means that 'truth is elusive'.[40] Whereas for the Christian, truth is not elusive but is to be found in Jesus (Jn 14:6; 19:37; Col 2:3): truth is Christocentric.[41]

For the Christian there are epistemological consequences that follow from the structure of reality. Among them the following.[42]

i. The existence of a transcendent God provides a locus of unchanging truth. Truth is not relative to time, place or culture, but to the creator God, who is the source of all truth.
ii. A purposeful creation implies that the knowledge we require to respond to God's calling for us is accessible.
iii. The order of creation means that knowledge is possible.
iv. The fact that creation has value suggests that human knowledge has value.

These assertions are of course faith commitments. This is not to denigrate them; the presuppositions at the heart of constructivism are just as much faith commitments!

What does it mean to be human? To be human is to struggle to try and live consistently with the world. It is a process of modifying our personal construction of reality as we engage in observation, interpretation and prediction, so that they 'allow better predictions in the future'.[43]

What is wrong? The problem for the constructivist is that our models of reality constantly need to be modified, they are not wholly consistent.

What is the remedy? The remedy is to be constantly modifying our constructions of reality through the processes of observation and interpretation. 'Salvation' comes through a scientific method.

From the above it becomes immediately apparent that constructivism as a philosophy does not sit comfortably with a Christian worldview.

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39. Wheatley p. 10.
40. Wheatley p. 10.
41. Arthur F. Holmes, *Contours of a World View*, (Erdmans, 1983).
42. For further discussion, see Holmes, *Contours of a World View*, ch. 8.
43. Pope and Watts, (1988), p. 103.

A relative problem

One particular problem is the relativist view of science that lies behind constructivism:

> '. . .a constructivist perspective draws on sociology of knowledge and philosophy of science in considering not only personal knowledge but public knowledge to be human constructions'.[44]

For a Christian, science is a God-given human activity whereby we explore and investigate God's good creation in an attempt to understand its order and structure. By its very nature as a human activity its results and conclusions can only be tentative, fallible and provisional; hence a *naive* realist view of science is untenable. This is the 'naive' idea that scientific laws and theories provide an accurate literal description of an objective world: it supposes that there is a one-to-one correspondence between theory and reality. One of the strengths of constructivism is that it exposes the fallacious nature of naive realism.

A *relativist* view is also flawed; because we are dealing with a God-given reality, which is not the product of social agreement. A relativist view is untenable because it is self-refuting; it rests on the absolute truth that there is no absolute truth![45] The theoretical physicist Paul Davies made this revealing observation:

> 'Few scientists would be willing to suppose that laws of physics are merely human inventions. To be sure, they are formulated by humans, but the physicist is motivated by the *belief* that laws of physics reflect some aspect of reality. *Without this connection with reality, science is reduced to a meaningless charade.*'[46]

Relativism undermines the very basis of scientific investigation. It denies that there is an objective reality to investigate. I would therefore want to suggest that a *critical* realist view of science is more appropriate for a Christian; that is: science provides us with a fallible description of an external world.[47] A critical realist viewpoint does justice to both epistemological subjectivity and metaphysical objectivity.

John Polkinghorne comes to a similar conclusion:

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44. R. Driver, 'Theory into practice II: A constructivist approach to curriculum development' in P. Fensham (ed.), *Development and Dilemma in Science Education*, (Falmer, 1988), p. 136.
45. See Roger Trigg, *Reason and Commitment*, (CUP, 1973).
46. 'Law and order in the universe', *New Scientist*, 15 Oct. 1988 p. 59; my emphasis.
47. For a defence of a critical realist position, see Ian G. Barbour, *Issues in Science and Religion*, (SCM, 1960) ch.6; John Polkinghorne, *Rochester Roundabout: The Story of High Energy Physics*, (Longman, 1989), ch.21.

> 'I take a critically realist view of our scientific exploration of the world. Such a position implies the possibility of gaining verisimilitudinous knowledge, which is reliable without claiming to be exhaustive. In that case, what we know and what is the case are believed to be closely allied; epistemology and ontology are intimately connected'.[49]

Another scientist and priest, Stanley Jaki, in his 1975–6 Gifford lectures, cites the following as one of the major lessons of the history of science:

> 'Just as no man can live by bread alone, no cosmologist (a term which includes all genuine scientists) can live without a realist notion of the universe as the totality of all interacting things'.[49]

Our knowledge of the world is imperfect, we will have to propose tentative and provisional models and explanations that at present represent what we know of reality; this however does not deny that there is any 'real world' 'out there'. Even though our access to it is imperfect. Our knowledge of reality is coloured by our worldview—'our spectacles behind our eyes'; in this sense then we have no *direct* access to the 'real world'. But a 'real world' does exist, it is not a human construction, despite von Glaserfeld *et al.*'s claim to the contrary.

If we have no access to the 'real world' then science becomes vanity. How can we collect data? There is nothing by which we can measure or judge the validity or truthfulness of our hypotheses, theories or laws. Constructivism denies we can know any God-given order to creation; and ultimately it denies the God who is faithful to his creation.

Scientific laws are not merely products of a scientist's imagination, as more radical constructivists maintain. God's reply to Job is apposite here:

> Did you proclaim the rules that govern the heavens or determine the laws of nature on the earth? (Job 38:33)

A distinction needs to be made between scientific laws and the God-ordained laws, decrees or ordinances that govern the universe (cf Ps 147:15–20).[50] Scientific laws are human approximations or representations of the way God upholds and structures his creation. Their usefulness is dependent on how accurate the approximations are. They are not human constructions imposed on reality. The aim of science then is to formulate these laws and make them explicit; an exercise that is

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48. John Polkinghorne, *Reason and Reality: The Relationship between Science and Theology*, (SPCK, 1991), pp. 41–2.
49. Stanley L. Jaki, *The Road of Science and the Ways of God*, (Scottish Academic, 1978), p. 276.
50. See Albert M. Wolters, *Creation Regained*, (IVP, 1986). For a brief discussion on the distinction between 'natural' and 'creational' laws, see Richard T. Wright, *Biology through the Eyes of Faith*, (Apollos, 1991).

only possible because we have 'faith in the lawfulness of reality and in a God who faithfully maintains his laws'[51] and in a God who enables us to have access to that reality, albeit dimly at times.

Conclusion

A full-blooded constructivist philosophy is patently at odds with a Christian perspective on science and a Christian view of reality. However, this does not mean we should dismiss constructivism out of hand.

Constructivism is correct in that it rejects a Lockian *tabula rasa* view of learning; pupils are not blank slates, sponges or empty buckets. Learning is, at least in part, an active process that at times requires concept change. Constructivism has also produced some fruitful work in attempting to understand the 'misconceptions' (to use the terms of a realist) or 'alternative conceptions/frameworks' (to use the language of a relativist) that pupils bring to the classroom.[52] To ignore these findings is surely irresponsible. Robin Millar correctly states:

> 'The constructivist approach offers an insight that is enormously valuable, in emphasizing that *any* knowledge is necessarily reconstructured by the learner in the learning process. We cannot teach a body of knowledge by direct transmission; the learner is always involved in reconstructing the meaning personally'.[53]

To focus on one aspect of the learning process, however, for example constructivism, to the exclusion of all others is idolatry: a partial truth is not the whole truth. The process of learning is multifaceted. We cannot reduce it to concept change. In this sense then constructivism is reductionistic; it focuses on only one aspect of the learning process and makes it all important. Constructivism as a (not *the*) theory of learning, stripped of its relativist baggage, does have a part to play in a distinctively Christian science course, but we must not bow down to its altar by being exclusively constructivist.

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51. M.D. Stafleu, *Time and Again*, (Wedge, 1980).
52. See, e.g., the works cited in Pope and Watts (1988) and in R. Driver and G. Erickson, 'Theories in action: some theoretical and empirical issues in the study of students' conceptual frameworks', *Stud. Sci. Educ.*, vol. 10 (1983), pp. 37–60; as well as the bibliography by Driver and Watts (1990).
53. Millar, (1989), p. 592.