seen as a further articulation of vital processes, one way that mind grows out of life.

A Few Final Words

Whitehead noted that the value of a formalism is that it lets you apply a practical method without concentrating too much on it; so that one's attention can be given to inventing and applying methods to other problems. Knowing how to add, for example, permits us to ignore the process and to focus on the meaning or significance of elements operated on. Whitehead asserted that that is true for the calculus. It is also true for SLIM–which generates dependably all relevant games playable given a particular player objective. That list can be filtered to permit focus on some subset of games of high interest–such as those won by the player. Computational procedures are formal, but the method itself is one more constructive than analytic. That may make it more apt for representing knowledge and its growth than analytic methods.

One would like to understand in detail what is in the brain and how that changes through interactions of the individual with the world and through interior interaction. This is surely at least as hard as asking how a specific photon "decides" to reflect from or pass through a surface. Even if one cannot explain human learning at a comparable level to that at which one can explain reflection:

- Given that the principle that co-generativity under specific algorithms provides the explanation of differential learnability, one should be able to articulate why learning is possible in specific domains on the basis of the internal relationships of schemes of representations and learning algorithms, the latter seen as transformations between the states of those relationships.
- This is a retreat from psychology to epistemology: others have retreated before us and still made a contribution, as physicists did in order to "resolve" the wave-particle duality.

Throughout this paper, the issue of whether or not simple descriptions can comprise "real science" has continually surfaced. Different people have different criteria for judging what work is scientific and what is not. Peirce, for instance, argued that science is primarily a question of intent, generally based on a real objective of finding out what is the case in the world, and that method is derivative though still significant. Exploring epistemology through computation is clearly scientific in intent (that is, by Peirce's criterion). It is also arguably scientific in method, as marked by its similarity to Feynman's explication of QED. One should ask of such work not "is it science?" as judged by some narrow criterion, but "is it good science? Is it important science?" Ultimately, that judgment must be made on the merits of the particular case.

Acknowledgements:

This paper is based on work and ideas developed over many years at diverse places. It was my privilege to meet Feynman many years ago when I studied at Caltech. Years later, I went to MIT to study with Minsky, directed to him by hearing of Feynman's interest in his work from a classmate of my student days. My doctoral research involved case studies of learning in Papert's laboratory at MIT, guided by his appreciation of Piaget and the intellectual program represented now by Minsky's book The Society of Mind, earlier a joint effort of Minsky and Papert. The influence of Papert, as epistemologist, remains deep here in specific ideas. On the suggestion of Minsky, I worked with Oliver Selfridge as an apprentice at computational modelling. Oliver's contributions to this work are pervasive; the first publication about SLIM bears his name as well as my own. Bud Frawley showed me how to do the recursive game extension at the heart of SLIM. Sheldon White and Howard Gruber encouraged my case studies and showed me links between my own intellectual heroes and others (Vygotsky and Lewin). Discussion over several years with Howard Austin, Robert B. Davis, Wallace Feurzeig, and Joseph Psotka have left their imprint on my work. Arthur Miller 's criticisms of an early draft and suggestions for revision were cogent and very helpful. Jim Hood, Mary Hopper, Gretchen Lawler, and Mallory Selfridge were kind enough to read early versions of this work and suggest useful directions for further development. No surprise then that the climate of MIT's AI Lab, GTE's Fundamental Research Lab, the Smart Technology Group at the Army Research Institute, and now Purdue have each made their special contribution to this effort. And if this effort reflects my admiration for one of the heroes of Caltech, perhaps it is not inappropriate to express my gratitude also to the memory of those mentors of my student days, Hunter Mead and Charles Bures, who first suggested I should take seriously the works of Langer and Peirce.

List of Works Referenced:

Barker, Roger G. and Herbert F. Wright (1951, 1966) One Boy's Day: a specimen record of behavior. Archon Books, Hamden, Ct.

Wright, Herbert F. (1967) Recording and Analyzing Child Behavior with ecological data from an American town (from an earlier volume titled MidWest and its Children). Harper and Row, New York.

Barker Roger G. (1968) Ecological Psychology: concepts and methods for studying the environment of human behavior. Stanford U. Press, Stanford.

Bourbaki, Nicholas (pseudonym) (1970) on The Architecture of Mathematics, cited in J. Fang Towards a Philosophy of Modern Mathematics. (Vol. 1, Bourbaki). Paidea, Hauppage, NY.

Brown, J. S. and D. Lenat (1983). AAAI Proceedings.

Feynman, Richard P. (1965) The Character of Physical Law. MIT Press. Cambridge, MA; 1967.

Feynman, Richard P. and A. R. Hibbs (1965) Quantum Mechanics and Path Integrals. McGraw Hill, Inc. New York

Feynman, Richard P. (1985) QED: The Strange Theory of Light and Matter. Princeton University Press. Princeton, N.J.

Goodall, J. (1971) In the Shadow of Man. Houghton Mifflin, Boston.

Goodall, J. (1990) Through a Window. Houghton Mifflin, Boston.

Langer, Susanne (1967) Mind: An Essay on Feeling. Vol. 1. Johns Hopkins University Press. Baltimore, MD.

Lawler, Robert W. (1980) The Articulation of Complementary Roles. MIT AI Lab Memo #594, (revised May, 1981). Cambridge, MA.

Lawler, Robert W. (1985) Computer Experience and Cognitive Development. John Wiley, Inc. New York.

Lawler, Robert W. (1987) Coadaptation and Cognitive Development. In Advances in Artificial Intelligence, Duboulay, Steels, and Hogg (eds.). Elsevier.

Lawler, Robert W. and O. G. Selfridge (1986). Strategy Leaning through Interaction. In Proceedings of the Nth Annual Cognitive Science Conference. Irvine, CA.

Lewin, Kurt (1935) The Conflict Between Galilean and Aristotelian Modes of Thought in Contemporary Psychology. In Dynamic Psychology: Selected Essays of Kurt Lewin, D. K. Adams and K. E. Zener (eds.) McGraw-Hill; New York.

McCulloch, Warren (1965) Through the Den of the Metaphysician. In Embodiments of Mind: Essays of Warren McCulloch, Seymour Papert (ed.). MIT Press, Boston.

Medawar, P.B. and J. S. Medawar (1983) Aristotle to Zoos. Harvard University Press, Cambridge, Mass.

Minsky, Marvin L. (1970) Form and Content in Computer Science. Journal of the Association for Computing Machinery, Vol. 17, No. 2, April 1970, pp. 197-215.

Minsky, Marvin L. (1986) The Society of Mind. Simon and Schuster. New York.

Papert, Seymour A. (1980) Mindstorms: Computers, Children, and Powerful Ideas. Basic Books. New York.

Piaget, Jean (1926) The Language and Thought of the Child.

Piaget, Jean (19xx) Needed: specific reference to the discussion of the centrality of coordinating schemata on the development of cross modal correspondances.

Piaget, Jean (1971) Biology and Knowledge. University of Chicago Press. Chicago.

Pierce, C.S. (1877) The Fixation of Belief. In Chance, Love, and Logic, Morris R. Cohen (ed). Brazilier Press. New York; 1923, 1956. (Originally published in Popular Science Monthly, November, 1877.)

Satinoff, N. (1978). Neural Organization and the Evolution of Thermo-regulation in Mammals. In Science, July 7, 1978.

Weyl, Hermann (1952) Symmetry. Princeton University Press. Princeton, NJ.