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ON "MISSING THE POINT" : A DEFENCE OF SEYMOUR PAPERT'S "EXERCISE IN AN APPLIED GENETIC EPISTEMOLOGY"

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ABSTRACT

This research report defends Seymour Papert's assertion that LOGO researchers have "missed the point" of the philosophy which underpins the LOGO learning environment. It establishes continuities between Papert's "exercise in an applied genetic epistemology" and Jean Piaget's genetic epistemology. Given this relationship the report argues that Papert's theory and research should be located within the Piagetian research programme. From this perspective Papert's assertion is justified to the extent that LOGO researchers have "missed the point" of his epistemological concerns and misconstrued the constructivist nature of the LOGO learning environment.

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted in partial fulfilment of the requirements for the degree of Master of Education by Coursework in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.

P. Rayner

(Name of candidate)

24 SEPTEMBER 1993

For Miriam Abrams

who loved, laboured and persevered.

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INTRODUCTION

In the late 1970's and early 1980's the field of computers in education experienced a veritable revolution. The growing availability of relatively inexpensive though increasingly more powerful microcomputers and the concomitant development of efficient operating systems and user-friendly computer languages 'unlocked' the true, general-purpose capacity of the computer. Following these significant technical innovations, a growing number of researchers and software developers began to extend the previously restricted use of the computer and to challenge the historically entrenched conceptions and uses of the computer. Although these challenges affected all domains of computer-use, it was especially in the field of education that the dogmatic thinking about the uses of computers attracted the most severe criticism.

One of the most articulate and influential critics of the prevailing dogmatism in the thinking and uses of computers in education was the mathematician and Artificial Intelligence (AI) researcher Seymour Papert[1] of the

[1] For biographical details see Goldberg (1991).

Massachusetts Institute of Technology (MIT). In his survey of the extant uses of computers in education, Papert (1979) identified three modes of computer-use which, he argued elsewhere, clearly showed that most technological innovations in education were tantamount to "inventing new gadgets to teach the same old stuff in a thinly disguised version of the same old way" (Papert, 1970/1980, p. 161). This criticism formed the basis of Papert's intervention in the field of computers in education, and to provide a context for understanding his work, the controversies that it has generated, and the issues that will be addressed in this research report, it is necessary to review some of his criticisms of the 'traditional' uses of computers in education.

According to Papert (1979), the first and most pervasive application of computers in education was "the computer as automated teacher", popularly known as Computer Aided Instruction (CAI). In this application the computer was used as a 'teacher', unwaveringly putting the child through drill-and-practice exercises (see for e.g., Suppes, 1966). The second, "the computer as simulated world", was less extensively used and in this application the child was exposed to computational simulations of real-life situations. The child was expected to manipulate various variables to see their effects in the simulated world and, by extension, to discover the effects of such manipulated

changes in the real world. The third application was "the computer as toy". In this application children were taught to program the computer by using a simple computer language such as BASIC[2] which, it was argued, would make them "computer literate" and provide them with skills deemed to be essential for survival in the "information age". Although Papert agreed that each of these applications could serve a valid (though limited) educational function, he was particularly concerned about the epistemological, psychological and educational assumptions which they embodied, and the conceptions of knowledge, learning and teaching which they promoted.

First, he argued, "the computer as automated teacher" was based on the view that knowledge consisted of a fixed body of discrete facts. Learning was therefore seen as a process of responding correctly to questions about discrete facts and the attainment of pre-determined, and strictly specified, behavioural objectives. Correspondingly, teaching was viewed as the systematic presentation of discrete bits of information and the effective management of "contingencies of reinforcement" to reinforce 'appropriate' behaviour. Secondly, Papert felt that although "the computer as simulated world" allowed the child some freedom to

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[2] BASIC (Beginners All-Purpose Symbolic Instruction Code) is one of the most popular computer programming languages.

discover aspects of knowledge for herself, this discovery was constrained by pre-defined boundaries. Knowledge was therefore presented as a fixed and immutable entity, while learning entailed the seemingly active discovery of pre-determined bits of information. Teaching, in this application, amounted to the presentation of purportedly open-ended information. Thirdly, Papert argued, by using a simplistic and restrictive computer language, "the computer as toy" undermined the complex nature of knowledge and restricted the child's creative potential. That is, the child was given some freedom to engage actively in the learning process but the nature of this activity was restricted because of the limited capacity of BASIC. Thus, insofar as the teaching of BASIC consisted of the 'transmission' of specific programming commands at specified times in the learning process, the notion of teaching as the transmission of pre-determined bits of information was reinforced.

From the foregoing analysis it was evident, according to Papert (1970/1980), that all the extant uses of the computer in education were firmly entrenched within a strict behaviourist framework and consistent with Skinner's ideas on programmed learning and teaching machines (Skinner, 1966; 1968; 1986). As such, Papert argued further, these

applications were akin to the "QWERTY phenomenon"[3] in the development of technology. Furthermore, they tended to encourage and legitimate what Papert called the "Pop-Ed Culture". This 'common sense' conception of learning and teaching promoted the view that children should not be taught to think about their thinking ("the don't think about your thinking paradox"); failed to discourage the student practice of making your mind a blank and waiting for an idea to come ("blank mind theories"); encouraged the idea that understanding comes in a flash ("getting-it theories"); and reinforced the notion that you either possess or lack the ability to master particular areas of knowledge ("faculty theories").

To challenge these anachronistic and essentially conservative uses of the computer to bolster the social and educational status quo, Papert (1970/1980; 1980) proposed an alternative "grander vision" of computers in education which

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[3] QWERTY is the arrangement of the alphabetic keys on the top row of the standard typewriter keyboard. Originally the most commonly used letters in the English language (D-H-I-A-T-H-E-N-S-O-R) were spread out to reduce typing speed and the concomitant jamming of the keys. Despite technological advances which eliminated this problem and the development of more rationally organised and ergonomically efficient keyboards (for e.g., the Dvorak Simplified Keyboard) the QWERTY keyboard became entrenched as the universal standard. This phenomenon, according to Gould (1991), is akin to the panda's obsolete thumb and demonstrates an important aspect of evolutionary history: "what was once a sensible solution becomes an oddity or imperfection in the altered context of a new future"(p. 66).

was based on the epistemological and psychological ideas of Jean Piaget and concepts derived from AI research. This vision included a practical and a theoretical dimension. The practical dimension was the LOGO[4] programming language which Papert developed with his associates at MIT as a computer-based learning environment which could facilitate children's construction of mathematical knowledge. The theoretical dimension was elaborated in his seminal book, Mindstorms: Children, Computers and Powerful Ideas (Papert, 1980); unpublished memoranda (Papert, 1971; 1973; 1976; Papert, et al., 1979); interviews (Hereford, 1982; White, 1985; Reinhold, 1986); journal articles and conference papers (Papert, 1980a; 1980d; 1981; 1982; 1984; 1984a; 1984b; 1986a; 1986b; 1987; 1988); co-authored articles (Franz & Papert, 1988; Turkle & Papert, 1990); and chapters in books (Papert, 1970/1980; 1972/1980; 1977; 1978/1980; 1979; 1980b; 1980c; 1986; 1987a; 1988a; 1991; 1991a)[5].

Following the favourable reception of Mindstorms and the 'endorsement' of LOGO by the influential computer journal Byte - which devoted an entire edition to the language and

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[4] To distinguish the original program from its more recent derivatives - i.e., Logowriter (Papert, 1986a); LEGO/Logo (Resnick & Ocko, 1991); *Logo (pronounced st r-logo) (Resnick, 1991); and MultiLogo (Resnick, 19 a) - the name "LOGO" will be capitalised throughout this research report.

[5] For a more complete listing of Papert's writings see Solomon (1987).

its philosophy (Byte, Vol. 7, No. 8, August 1982) - LOGO rapidly gained near-universal acceptance in the field of computers and education. Educational administrators, teachers, researchers and computer enthusiasts began to agitate for its incorporation into the school curriculum and a host of researchers began to investigate the educational efficacy of LOGO. Consequently, during the decade 1980 - 1990, a wealth of research[6] on LOGO and education was generated (for a review of this literature see Sorkin, 1984; Palmgren, 1985; Abelson, et al., 1986; Forman & Pufall, 1988; Harper, 1989; Schuyten & Valcke, 1990; and Harel & Papert, 1991)[7].

This research, like the more general research on learning from media (see for e.g., Clark & Sugrue, 1990), has, however, been fraught with "controversy and paradox" (Lepper & Gurtner, 1989). The qualitative research findings on children's constructive activity in the LOGO environment

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[6] An indication of the magnitude of this research literature can be inferred from Summers' (1985) bibliometric analysis of the growth of journal literature on computers and education and the bibliography on LOGO compiled by Lough (1985).

[7] It should be noted that the LOGO research literature is only a subset of a more general literature devoted to computer programming and its effects on cognition. For reviews of this literature see Hassett, 1984; Pea, 1984; Linn, 1985; Linn & Dalbey, 1985; Dalbey & Linn, 1985; Underwood & Underwood, 1987; Salomon & Perkins, 1987; Johanson, 1988; Dudley-Marling & Owston, 1988; Salomon & Perkins, 1989; Martin & Hearne, 1990; McCoy; 1990.

conducted by Papert, his associates and other researchers who share this methodological orientation (e.g., Papert, et al., 1979; Watt, 1979; Turkle, 1984; Turkle & Papert, 1990; Lawler, 1981; 1985; Lawler et al., 1986; Forman & Pufall, 1988; Franz & Papert, 1988; Hoyles & Sutherland, 1989; Harel & Papert, 1991), have either been supported or challenged by researchers who adopt a quantitative and experimentally based research method to verify the effects of LOGO on children's thinking in general and on their problem-solving skills in particular (e.g., Gorman & Bourne, 1983; Clements & Gullo, 1984; Siann & Macleod, 1986; Clements, 1986; 1987; Horton & Ryba, 1986; Mayer & Fay, 1987; Pea, 1987; Pea, Midian & Kurland, 1987; Rieber, 1987; Lehrer, Guckenberg & Lee, 1988; Poulin-Dubois, McGilly & Schultz, 1989)[8]. These contradictory empirical findings have in turn generated, amongst others, debates about appropriate research methods to verify the effects of LOGO on cognition (e.g., Salomon, 1984; Mawby, 1985; Clark, 1985; Bracey, 1988; Papert, 1986; Becker, 1987; Pea, 1987; Walker, 1987; Maddux, 1989; Salomon, 1990; Watt, 1990; Clark, 1991), and the role of teaching in the LOGO environment (e.g., Tetenbaum & Mulkeen, 1984; Leron, 1985; Simon, 1987; Hoko, 1986 De Corte & Verschaffel, 1989).

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[8] General reviews of some of this literature can be found in Krasnor & Mitterer (1984); Michayluk (1986); Simon (1987); Lepper & Gurtner (1989); Chang (1990).

In particular, Papert's theoretical ideas have been criticised as "rhetorical" (Brown, 1984); "abstrusely phrased" and "metaphysical" (Rezanson & Dawson, 1985); and, very importantly, failing to take "some of the major premises of Piaget's theories about the development of learning" into account (Rousseau & Smith, 1981, p. 52). Also, the critics contend, Papert's claims about the cognitive and educational benefits of LOGO are based on "anecdotal" evidence (see Winer & de la Mothe, 1983; Krasnor & Mitterer, 1984; Lepper & Gurtner, 1989), informed by a "technoromantic" view of computers (Simon, 1987), and predicated on "a naïve faith in the educational efficacy and adequacy of rich environments" (Ragan, 1989, p. 32) which promised more than it has delivered (Hawkins quoted by Hassett, 1984).

In response to some of these criticisms Papert (1986; 1987) has repudiated the purported promises about the value of LOGO to promote certain thinking skills in children as having no support in his writings. More importantly, he has charged his critics with engaging in "technocentric"[9] thinking (Papert 1987 1988) and thereby, "missing the

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[9] The term "technocentric" is derived from Piaget's notion of egocentricity or centredness in the child and is used by Papert to signify the propensity to focus exclusively on the technical object while ignoring the context of its use.

point" (Papert, 1986) of the LOGO philosophy. This tendency, he contends, is evident in both the exclusive focus on LOGO and the computer as 'agents' capable of affecting children's cognition in a simple and predictable way, and in the use of a "treatment model"[10] research methodology to verify the attainment of such presumed effects. With regard to the former Papert believes that most LOGO researchers have "missed the point" that LOGO is only a "cultural element" within the broader "learning culture" that may help children to construct the kinds of (mathematical) knowledge which our "mathophobic" society considers difficult to master. Similarly, in their use of a research methodology which attempts "to reduce what are really the most important components of educational situations - people and cultures - to a secondary, facilitating role" (Papert, 1987, p. 23), these researchers have "missed the point" of the complex "cultural process" of learning (with computers). Thus, Papert contends, the 'negative' results recorded in the LOGO literature are more a function of technocentric thinking and positivist research methods than a 'failure' of LOGO to fulfil its purported promises.

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[10] The "treatment model" is the classical experimental research design involving a control and an experimental group which is exposed to a particular "treatment" to verify the efficacy of the treatment in relation to the "untreated" control group.

In their rebuttals to the foregoing criticisms LOGO researchers have in turn criticised what they believe to be Papert's "narrow construal of what constitutes experimental research" (Pea, 1987, p. 6), argued for "the importance of a methodology that maximises falsifiability" in LOGO research (Becker, 1987), urged Papert to recognise the necessity of "sound research and evaluation" to justify the educational use of LOGO (Walker, 1987, p. 10), and so on.

Although superficial, the foregoing account conveys a sense of the nature and scope of the "controversy and paradox" surrounding Papert's ideas and LOGO research. Specifically, it shows that there is a continuing dispute centred on Papert's specific claims about the cognitive benefits of LOGO and computers and an equally contentious debate concerning his research methods to authenticate these claims. Aspirant researchers who are new to this area of research are therefore faced with the difficult problem, "what should we believe, and why?" (Simon, 1987). To resolve this problem I believe that it is necessary to deal with the following questions, amongst others, raised by the LOGO literature:

- What are the cognitive benefits (if any) of using LOGO and are these purported benefits supported by Papert's writings?

- Is Papert justified in his assertion that (most) LOGO researchers have "missed the point"?

- What is the point of the LOGO enterprise?

A possible way of answering these questions and resolving the disputes outlined above is to recognise that these controversies are not unique to Papert's ideas and LOGO research. Very interestingly, these controversies seem to 'recapitulate' the earlier (and continuing) debates about the interpretation of Piaget's ideas, the validity of his clinical research methods and findings, and the application of his theory to education. Thus, insofar as this 'recapitulation' can be shown to be correct, it would follow that the re-conceptualisation of Piagetian theory and research on the basis of Lakatos's (1974) "sophisticated falsificationism" may help us to resolve the controversies within the LOGO research domain.

Proceeding from the foregoing premise I will defend Papert's assertion that LOGO researchers have "missed the point" by locating his ideas and research on the LOGO learning environment within the context of the Piagetian research programme. Specifically, I will argue that most researchers have failed to see the continuities between Piaget's genetic

epistemology and Papert's "exercise in an applied genetic epistemology" (Papert, 1980, p. vii)[11] as an elaboration of aspects of the Piagetian research programme in the context of a computer-rich world. This failure, I will further show, has in turn led to (i) a misunderstanding of the epistemological origins and nature of Papert's ideas about computers and cognition; (ii) the misrepresentation of the LOGO programming language as a variant of Computer Aided Instruction; and (iii) the misinterpretation of his research as an exclusively psychological and educational exercise rather than a means for answering, among others, the questions raised by his elaboration of the Piagetian research programme. In view of these shortcomings I will argue that Papert is justified in asserting that LOGO researchers have "missed the point" and in repudiating the claims about the cognitive benefits of LOGO imputed to him. Lastly, on the basis of my re-casting of Papert's work as an elaboration of the Piagetian research programme I will argue that simple falsifications do not dis-confirm a theory (Lakatos, 1974) and that the conditions that may refute some of Papert's theoretical assertions have not yet been realised.

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[11] The complete statement reads "an exercise in an applied genetic epistemology expanded beyond Piaget's cognitive emphasis to include a concern with the affective". My emphasis in this research report will be on the cognitive dimension of Papert's work and will exclude the affective in order to restrict the scope of the report.

To defend the foregoing claims I will first present an exposition of Piaget's genetic epistemology and the Piagetian research programme as the framework for understanding Papert's ideas and research. Secondly, I will provide a detailed discussion of (a) Papert's elaboration of the Piagetian research programme, and (b) the LOGO computer language and learning environment and the nature of the constructivist activities it intends to promote. Finally, I will argue for the necessity to locate Papert's work within the framework of the Piagetian research programme as the basis for future research.

IN DEFENCE OF PAPERT'S "EXERCISE IN AN APPLIED GENETIC EPISTEMOLOGY"

From its inception a central concern of the LOGO research literature has been a perceived "fundamental tension" (Leron, 1985) between Papert's Piagetian view of "successful learning" as "a process that takes place without deliberate and organized teaching" (Papert, 1980, p. 8), and his belief that the computer and LOGO may provide children with the means to construct "powerful ideas"[12] such as proceduralisation. Interpreting Papert's conception of learning as "learning without teachers" (Papert, 1986 [emphasis in the original]), numerous researchers (e.g., Krasnor & Mitterer, 1984; Pea & Kurland, 1984; Leron, 1985; Simon, 1987) found that children learning LOGO "without being taught" failed to acquire the powerful ideas which Papert purportedly saw as a necessary outcome of using LOGO. This failure, according to some of these researchers, was a direct consequence of Papert's adherence to a Piagetian conception of learning. Consequently they proposed either the adoption of "quasi-Piagetian learning (QPL) - which assumes a more active role for teachers and learning

[12] In Papert's (1980) understanding "powerful ideas" such as "debugging" (which will be discussed later), "planning", "proceduralisation", etc., are "intellectual tools" which may facilitate the child's construction of knowledge. These "powerful ideas", I would argue, are akin to Vygotsky's (1978) "psychological tools", i.e., the means through which humans come to master their intellectual and physical activity.

materials" (Leron, 1985, p. 28) or the rejection of the "rigid, stereotypic, out-dated views of Piaget's theory" (Watson, Nida & Shade cited by Shade & Watson, 1990, p. 377) in favour of "the knowledge generated by new information-processing approaches to learning and cognition" (Simon, 1987, p. 118), for example.

Leaving aside for now the fact that the above researchers, amongst others, have "missed the point" of Papert's claims about the outcomes of using LOGO (i.e., as possible and not necessary outcomes), I believe that the perceived "tension" is more a function of these researchers' (mis)understanding of Piaget (and Papert's particular interpretation of Piaget) than a "tension" between 'process and outcome' in Papert's thinking. Very interestingly, this misunderstanding of Papert appears to be a 'recapitulation' of the earlier misunderstanding (and misrepresentation) of Piaget (Groen, 1978; De Vries, 1978; Kamii & De Vries, 1978; Johnson & Hooper, 1982; Duckworth, 1987). That is, as with Piaget where researchers fused his epistemology with his psychology (Vonèche, 1990) and interpreted, for example, his findings on young children's inability to conserve continuous volume as a rationale for teaching conservation skills, LOGO researchers interpret children's current failure to acquire "powerful ideas" as entailing the necessity to teach these ideas more formally. In the earlier case the researchers failed to see Piaget's epistemological assertion about the

biological and dialectical necessity (Kitchener, 1985) for (human) biological organisms to construct the knowledge of conservation as they develop. Similarly, concerning Papert's thinking, researchers have "missed the point" of his essentially epistemological claim about the potential impact of computers and LOGO on the development of cognition and, consequently, they have interpreted his work as an exclusively psychological and educational enterprise. As such, I would argue, Piaget's assessment of Flavell's (1963) exposition of his thinking as "perhaps too exclusively psychological and insufficiently epistemological" (pp. viii - ix) is equally applicable to the bulk of the LOGO research.

This "insufficiently epistemological" interpretation of Papert's work, I believe, is a consequence of the more general tendency to 'psychologise' Piaget's epistemology and to disregard the ongoing debates and developments within Piagetian theory and research (e.g., Gallagher & Easley, 1978; Sigel, Brodzinsky & Golinkoff, 1981; Modgil & Modgil, 1982; Scholnick, 1983; Overton, 1983; Neimark, DeLisi & Newman, 1985; Bearison & Zimiles, 1986; Inhelder, de Caprona & Cornu-Wells, 1987; Liben, 1987). These tendencies apart, most LOGO researchers also appear to subscribe to a "naïve falsificationist" conception of scientific research which disregards Lakatos's (1974) view that "purely negative, destructive criticism, like 'refutation' does not eliminate a programme" (p. 179). With regard to the former contention I believe that with

the exception of some researchers (e.g., Feuerzeig, 1986; Groen, 1978; Groen & Kieran, 1983; Kay, 1991; Lawler, 1981 & 1985; Lawler, et al., 1986; Schank, 1986; Solomon, 1986; Turkle, 1984; and the contributors to Forman & Pufall (1988) and Harel & Papert (1991)), the overwhelming majority of LOGO researchers bring an empiricist "reading" of Piaget to bear on Papert's thinking. In this process they misconstrue not only Piaget's theory but ignore Papert's (1980) stipulation that his interpretation of Piaget's theory is "unorthodox" and that the educational implications which he derives from this interpretation are "very unorthodox". Consequently, these researchers "miss the point" that Papert's primary concern is to uncover a more "revolutionary" Piaget - i.e., Piaget the epistemologist "whose epistemological ideas might expand the known bounds of the human mind" (Papert, 1980, p. 157) - rather than the "conservative" Piaget who shows what children lack at particular stages in their development. With their "naïve falsificationist" research orientation these researchers have further treated Papert's theory as a single theory which, they believe, has been invalidated through the 'refutation' of some of its hypotheses. What these researchers "miss" in this regard is that Papert's theory is part of a continuous "series of theories" which make up the Piagetian research programme. As such, it can only be evaluated as part of this series of theories and even then, according to Lakatos (1974), it is necessary

to recognise that we are dealing with "a long and often frustrating process" (p. 179).

To address these misunderstandings in the LOGO research literature, and to show the essentially epistemological nature of Papert's claims about the effects of computers and LOGO on cognition, I would argue that it is imperative to locate his work within the framework of the Piagetian research programme. Consequently, my defence of Papert's "exercise in an applied genetic epistemology" will proceed from an exposition of Piaget's genetic epistemology and the Piagetian research programme. Thereafter, I will provide a detailed discussion of Papert's project as an elaboration of the Piagetian research programme in view of the computerisation of modern society. I will then discuss the LOGO programming language and the nature of the activities it intends to promote. Lastly, I will review the questions posed in the introduction of this research report and argue that Papert is justified in his assertion that LOGO researchers have "missed the point".

Part 1

Piaget's Genetic Epistemology[13]

Genetic epistemology, according to Piaget, is the study of both (Kitchener, 1981) the transitions "from a lower level of knowledge to a level that is judged to be higher" (Piaget, 1970, p. 13) and "the mechanisms of the increase of knowledge" (Piaget quoted by Kitchener, 1981, p. 402). In pursuit of these objectives Piaget proceeds from the assumption that there is a "similarity between biological structure/function and epistemological structure/function" (Kitchener, 1981, p. 404) and contends that the biological methods used in comparative anatomy - viz., "the study of homologous structures in adult organisms . . . and [the study of] the ontogenetic development of the individual" (ibid, p.404) - are comparable, by analogy, to the methods to be used in the study of the transitions and mechanisms in the growth of knowledge. From this perspective genetic epistemology is thus "a mental comparative anatomy" (Kitchener, 1981) which studies the evolutionary development of the structural relationships between certain concepts. When

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[13] In view of my primary intention to elucidate Papert's interpretation of Piaget's thinking my discussion of genetic epistemology will be superficial. For more in-depth expositions see for example Rotman (1977); Vuyk (1981); Atkinson (1983); Kitchener (1981; 1985; 1986); Chapman (1988); and Vonèche (1990).

this method proves to be inadequate it is supplemented by the study of the origin and development of these concepts in the individual.

The first method, the historico-critical method, is concerned with the historical origins and development (i.e., historiogenesis) of the structural relationships between those concepts (e.g., time, space, causality, logic, etc.) that Kant considered necessary, especially for scientific thinking (i.e., the level of knowledge "that is judged to be higher"). This method, Piaget contends, is not sufficient to the task and should be supplemented by an investigation of the origin and development of the above concepts in the individual (i.e., psychogenesis). Such an investigation, Piaget believes, necessarily entails genetic psychological research and therefore it is imperative for genetic epistemology "to take psychology seriously". This research is not, however, an end in itself but is intended "to provide answers to questions about genetic epistemology" (Kitchener, 1986, p. 27). Also, in its endeavour to uncover "the mechanisms of the increase of knowledge" it is only concerned with those concepts which Kant considers necessary for scientific thinking. Lastly, and very importantly, although such research is conducted with real individuals, Piaget argues that

> a fundamental epistemological distinction must be introduced between two kinds of subjects or two levels of depth in any subject. There is the 'psychological subject' centred in the conscious

> ego whose functional role is incontestable, but which is not the origin of any structure of general knowledge; but there is also the 'epistemic subject' or that which is common to all subjects at the same level of development, whose cognitive structures derive from the most general mechanisms of the co-ordination of actions. (Piaget in Beth & Piaget, 1966, p. 308)

Thus, on the basis of the caveats introduced above, the genetic psychological research conducted within genetic epistemology is concerned with "the psychogenesis of the fundamental categories of thought in the epistemic subject from infancy to adulthood" (Kitchener, 1981, p. 409).

The methods and objects of study of genetic epistemology outlined above raise, however, the problem of the relationship between historiogenesis and psychogenesis. Does psychogenesis recapitulate historiogenesis according to the biogenetic law that "ontogeny recapitulates phylogeny"? Are the two strands of development completely autonomous, or are they related in more complex ways? Piaget's research on the stages of development in both domains showed that sometimes there are "structural parallels" and "partial isomorphisms" in the sequence of their occurrence (e.g., Piaget & Garcia, 1989) but at other times the sequence in historiogenesis is completely inverted in psychogenesis[14] (Kitchener, 1985). This

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[14] This phenomenon was found in the development of geometric knowledge and is quite important for understanding Papert's thinking. This issue will be dealt with in greater detail in my discussion of Papert's "applied genetic epistemology".

complex relationship raises a further question about the particular sequences of development discovered by Piaget. Are these sequences biologically or logically necessary in their occurrence? According to Kitchener (1985) an explanation of biological necessity is inadequate, while an argument in favour of a logical necessity is unable to account for the inversion of the sequence in some instances. Consequently, according to Kitchener, the sequence of stages discovered by Piaget could be interpreted as dialectically necessary. According to this interpretation

> development should always (and does normally) attain its goal, even though this goal is not predetermined or narrowly fixed a priori. Given the constraints imposed by certain orthogenetic principles together with the initial and boundary conditions, the particular way the goal is attained is open to our free and creative construction. (Kitchener, 1985, p. 13)

The foregoing problems notwithstanding, Piaget contends that the explanatory mechanisms involved in the domains of historiogenesis and psychogenesis are the same. That is, the explanatory mechanisms obtained by psychological research on the origin and development of the concepts of time, space, causality, etc., in the individual also apply to the historical origins and development of the structural relationships between these concepts. Thus, having outlined the nature and scope of genetic epistemology, it is necessary to look more closely at the "mechanisms of the increase of knowledge".

Following from the presupposition of a similarity between "biological structure/function and epistemological structure/function" mentioned above, Piaget contends that there is a 'similarity' between biological and epistemological adaptation and that the latter is a necessary outcome of the former. Consequently, his genetic psychological research on the development of the concepts necessary for scientific thinking in the individual proceeds from the biological premise that it is functionally necessary for living organisms to maintain their continued viability (Von Glaserfeld, 1984; 1988) in an uncertain and continually changing environment. More specifically for Piaget

> the organization of all life is characterised by unstable equilibria that are continuously modified by contact with the environment, but nevertheless tend toward stability even as they are modified by the environment. (Chapman, 1988, p. 23)

Given the disequilibria, continuous modification, and tendency toward equilibrium of all life forms, the important questions for Piaget are, "How do living organisms maintain the integrity of their internal structural organisation despite the instability created within them by a continuously changing environment?", and secondly, "How do living organisms modify their internal structural organisation in response to a constantly changing environment to ensure not only their continued viability but also to maintain continuity between newer and existing forms of structural organisation (albeit on

a higher level of equilibrium)?" In both instances, Piaget argues, it is an organism's ability to auto- or self-regulate which helps it maintain an equilibrium, however incomplete, between already constructed structures and between these structures and a changing environment. This idea of auto-regulation as the "underlying causal mechanism" (Kitchener, 1985) or "generative mechanism" (Harré & Secord, 1972; Miller, 1987; 1989; 1989a) of development is crucial for Piaget. In his view it is the mechanism responsible for the construction of new structures and more complex forms of internal organisation as well as a conservative force that strives to maintain the integrity of existing, viable structures in the organism. This universal tendency of organisms to maintain an equilibrium between themselves and the environment is also important for Piaget because it is a means for distinguishing development - i.e., "change that led from a lower level of equilibrium to a higher one" (Chapman, 1988, p. 8) - from mere change.

According to Piaget the biological mechanisms involved in this tendency towards equilibrium are the complementary processes of assimilation and accommodation. In the process of assimilation the organism incorporates external 'stuff'[15] into previously constructed structures,

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[15] The use of this term is deliberate and intended to signify a view I share with Von Glasersfeld (1984; 1988) about Piaget's ontology versus his epistemology. That is, Piaget does not deny the existence of an external world

and through the modification of these structures the organism accommodates the structures to external 'stuff'. At some point, however, novel 'stuff' in the environment defies the processes of assimilation and accommodation thus causing a disequilibrium in the organism. To re-establish its equilibrium the organism is compelled to auto-regulate or equilibrate on a higher level. In this process existing structures are transformed into more elaborated structures which retain their continuity with older structures while simultaneously extending the range of 'stuff' that can be assimilated and accommodated into the newly elaborated structures.

Although the processes of assimilation, accommodation, equilibrium, and equilibration are used to explain the biological adaptation of organisms to a changing environment, Piaget sees the same processes operating on the epistemological level. What this means is that the epistemic mechanisms of assimilation, accommodation, equilibrium, and equilibration are responsible for the increase of knowledge and the transitions from a lower to a higher level of knowledge in the epistemic subject from infancy to adulthood. Using these 'mechanisms', the knowing subject actively constructs its own knowledge and

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but argues that we can only come to know it through our own constructions. Hence, the external world is initially undifferentiated "stuff" and it is only through a knowing subject's own constructions that the external world becomes known. (cf. Piaget's account of the development of object permanence in the child.)

in this process it passes through an invariant sequence of epistemic stages of development, viz., the sensori-motor, pre-operational, concrete operational, and formal operational stages.

To verify whether these epistemic mechanisms "have an instantiation at all", Piaget spent the larger part of his life in genetic psychological research and, in the process produced, a psychological theory of the development of intelligence. This research, as noted above, was only a means for answering the questions about the mechanisms involved in the transitions "from a lower level of knowledge to a level that is judged to be higher" and was not an end in itself. However, despite Piaget's stated purpose, most psychologists saw his work as an exclusively psychological enterprise. Consequently, they attempted to replicate his research using more rigorous experimental research methods or to apply it directly to educational practices. In both instances the results were generally "negative" or "inconclusive" and an increasing number of psychologists began to doubt the scientific validity of Piaget's theory and research. This doubt and the subsequent rejection of Piaget's theory raise numerous questions about the nature of scientific research. To address these problems researchers such as Groen (1978), Rowell (1983), and Beilin (1992), among others, have argued that Piaget's work should be conceptualised as a Lakatosian research programme. In the next section, therefore, I will discuss

the Piagetian research programme as a basis for understanding Papert's theory and research.

The Piagetian Research Programme

In his metatheoretical analysis of the nature and progress of science Lakatos (1974) contends that scientific research is not based on a single theory but "*a succession of theories*. . . usually connected by a remarkable *continuity* which welds them into *research programmes*"(Lakatos, 1974, p. 132 [emphasis in the original]). Such research programmes, he further believes, include some methodological rules which proscribe certain avenues of research (*negative heuristic*), while other rules propose avenues of research to follow (*positive heuristic*). The negative heuristic is based on a methodological decision which renders certain theoretical assumptions incapable of refutation. These assumptions, Lakatos contends, constitute the invariant *hard core* of the research programme and are common to the growing succession of theories in the programme. The hard core is further shielded by a *protective belt* of *auxiliary hypotheses* generated by the succession of theories within the programme and it is these hypotheses "which ha(ve) to bear the brunt of tests and get re-adjusted, or even completely replaced, to defend the thus-hardened core" (p. 133). The positive heuristic, in contrast, consists of methodological suggestions on how the "refutable variants" or auxiliary hypotheses of the

research programme are to be developed, modified or changed.

According to Lakatos a research programme is 'progressive' if it is able to increase its content through a *consistently progressive theoretical problemshift* (i.e., a capacity to make novel predictions consistently) and an *intermittently progressive empirical shift* (i.e., the occasional confirmation of at least some of those novel predictions). In contrast, a programme is 'degenerate' if it does not increase its theoretical content and consistently fails to discover new phenomena. If this happens the 'degenerate' programme will eventually be superseded by an alternative and more 'progressive' research programme.

Although superficial, the foregoing account of Lakatos's conception of "the methodology of scientific research programmes" adequately captures his alternative to the naïve falsificationist view of the nature and progress of scientific research that tends to dominate mainstream psychological research, amongst others. The latter tendency notwithstanding, a number of researchers (e.g., Groen, 1978; Rowell, 1983; Beilin, 1992) have argued that Lakatos provides "a useful integrative perspective" (Rowell, 1983, p. 61) for understanding Piaget's theory and research. In agreement with these researchers I would contend that this perspective may further help us to place Papert's theory and research within its proper

rigetian context as well as showing why, on a theoretical and empirical level, LOGO researchers have "missed the point". Given the latter intentions, my exposition of the Piagetian research programme will be brief and I will concentrate only on those aspects of the programme that are directly pertinent to Papert's theory and research.

If we keep in mind Piaget's fundamentally epistemological concerns and his view of himself as "one of the chief 'revisionists of Piaget'" (Piaget, 1983, p. 703), it is no surprise that his psychological theory of cognitive development is not a single, monolithic and unchanging entity, but a theory that went through continual change (Beilin, 1992). In its quest to answer the epistemological questions discussed above, the psychological theory (and its related empirical research) passed through four phases and in each of these phases something new and important was added (Beilin, 1992). However, despite these significant changes, the theory retained an essential continuity in its basic assumptions and purpose. Consequently, in the opinion of Groen (1978), Rowell (1983) and Beilin (1992), Piaget's enterprise "is more than a theory: it is a research programme on a vast scale" (Beilin, 1992, p. 191).

The *hard core* of this research programme is primarily epistemological (Groen, 1978) and contains a number of hypotheses about the "similarity between biological

structure/function and epistemological structure/function"; the relationship between the origin and growth of scientific knowledge and the development of intelligence in the individual; the idea that knowledge is actively constructed by a knowing subject through its activity with objects in the external world and that the development resulting from such construction would follow a definite sequence; and, most importantly, the contention that equilibration is the generative mechanism responsible for the increase of knowledge in the individual as well as the transitions from a lower level of knowledge to a level that is judged to be higher. These (and other) core assumptions are 'protected' from refutation by the negative heuristic of "epistemological triviality" (Groen, 1978), which disqualifies experimental research which fails to deal with "epistemologically significant" tasks, and the negative heuristic of the "dialectical necessity" of the sequence of the stages of development. That is, all else being equal, development will always follow a particular sequence as a result of equilibr , and in the event of structures emerging outside this sequence, they should be seen as either temporary or only capable of surviving if they merge with the structures of the main sequence of development (Groen, 1978). The positive heuristic of the programme includes working towards a constructivist genetic epistemology (Rowell, 1983), using the clinical method to explicate the underlying structures of the individual's performance, finding correspondences between

the development of scientific knowledge and the development of intelligence in the individual, and to look for 'aberrant' structures as the explanation for empirical results which are not consistent with the predictions of the hard core.

Despite the waning popularity of Piaget's theory and the competition presented by alternative theories, Beilin (1992) maintains that "the theory is still very much a contending presence in the free-for-all that defines current psychological research" (p. 192). As such, Rowell (1983) and Beilin (1992) agree that the Piagetian research programme continues to display a consistently progressive theoretical problemshift with regard to the continuing refinement and elaboration of the concept of equilibration (Moessinger, 1978; Rowell, 1983) and the significant changes to the theory which are becoming increasingly evident as more of Piaget's posthumous publications appear in English (Beilin, 1989; 1992). Correspondingly, the research programme displays an intermittently progressive empirical shift not only as the already formidable body of empirical data increases with Piaget's posthumous publications but also in the continuing research endeavours of those who 'identify' with this research programme (see for e.g., Gallagher & Easley, 1978; Sigel, Brodzinsky & Golinkoff, 1981; Modgil & Modgil, 1982; Scholnick, 1983; Overton, 1983; Neimark, DeLisi & Newman, 1985; Bearison & Zimiles, 1986; Inhelder, de Caprona & Cornu-Wells, 1987; Liben, 1987).

Thus, contrary to Watson, Nida and Shade (quoted by Shade & Watson, 1990, p. 377) who want to discourage educators from relying upon the "rigid, stereotypic, out-dated views of Piaget's theory", the Piagetian research programme has not degenerated nor been superseded by an alternative theory with greater explanatory value. In this regard Papert's elaboration of the research programme to include newer epistemic objects (i.e., computers) for subjects to act on is a significant contribution to the progressive theoretical problemshift and progressive empirical shift of the programme as a whole. To understand the nature of this contribution the next part of this research project will be devoted to Papert's "exercise in an applied genetic epistemology".

Part 2

> Programmed instruction is indeed conducive to learning, but by no means to inventing, unless, following S. Papert's experiment, the child is made to do the programming himself.
>
> Jean Piaget (1973, p. 7)

> The context of human development is always a culture, never an isolated technology. In the presence of computers cultures might change and with them people's ways of learning and thinking. But if you want to understand (or influence) the change you have to center your attention on the culture - not on the computer.
>
> Seymour Papert (1987, p. 23)

Papert's "Exercise in an Applied Genetic Epistemology"

In contrast to Papert's earlier writings which provided only tantalising suggestions of the relationship between his work and the Piagetian research programme, a more recent publication - appropriately entitled "The Conservation of Piaget" (Papert, 1988) - clearly demonstrates his allegiance to the hard core of this research programme:

> Whether one has conservation of Piaget will depend on what one perceives as most important in the thinking of the great master. My own view is that the essential aspects of his work have not fallen by the wayside. On the contrary, they are stronger and more relevant than ever. (Papert, 1988, p. 3)

At the same time, however, Papert contends that the research on computational objects and the different forms of activity that they engender in children do challenge aspects of Piaget's thinking and therefore

> some of what Piaget believed will have to be changed. But whether one sees this as disproving Piagetian theory or as elevating it to its next stage of development depends on what one counts as most important in Piaget. (ibid)

From this and subsequent writings (Papert, 1991; 1991a), it is clear that Papert does not see the 'disconfirming' evidence generated by this new area of research as disproving the core assumptions of Piaget's genetic epistemology. Instead, he believes that the 'extension' of the research programme to include "objects-to-think-with" (Papert, 1980) or "epistemic objects" (Lewin, 1987) such as computers and LOGO have elevated it "to its next stage of development", i.e., it has contributed significantly to the progressive theoretical problemshift and progressive empirical shift of the research programme. This assertion notwithstanding Papert has not, as far as I have been able to ascertain, systematically shown the relationship between his work and the Piagetian research programme. Thus, as a first foray into this area, my exposition of Papert's "exercise in an applied genetic epistemology" will be exploratory. In the first section I will discuss the hard core, genetic epistemological assumptions of his project and then look at his "unorthodox" interpretation of Piaget. After that

I will elucidate the "applied" dimension of his work by examining the LOGO programming language and the forms of activity that it intends to promote. The resultant framework will, I believe, clearly establish the veracity of Papert's assertion that LOGO researchers have "missed the point" of his theory and research.

Given Papert's numerous writings that deal with "Piagetian learning" and "constructionism" I believe that there can be no dispute about his unqualified acceptance of the constructivism and its underlying causal mechanism, viz. equilibration, which make up the hard core of the Piagetian research programme. In fact, in 1963 Papert had already argued that "even if Piaget's hypothetical construct of equilibration appears wrong or incomplete, it will have to be rsplaced by another theory of equilibration" (Papert quoted by Moessinger, 1978, p. 265). Although the mechanism of equilibration is assumed without further discussion in his writings on computers and learning, the foregoing quote clearly shows that Papert accepts it as the generative mechanism responsible for the growth of scientific knowledge and the development of intelligence in the individual. Following from this he therefore concurs with Piaget's view of a relationship between the growth of scientific knowledge and the development of intelligence in the individual (Papert, 1980).

These basic agreements notwithstanding, Papert (1980) challenges Piaget's (1964) conception of the relative unimportance of social factors in determining the invariant sequence of the stages of ontogenetic development and, very interestingly, points to the possibility of the inversion of this sequence and the development of new cognitive structures as a consequence of significant social change. At first glance the notion of an inverted sequence of development appears to go against the negative heuristic which is concerned with the necessity of the sequence of the stages of development and seems to threaten the integrity of the hard core of the Piagetian research programme as a whole. However, if we keep in mind Piaget's own research on the ontogenetic development of geometric knowledge and his explanation of its relation to the historiogenetic sequence, Papert's claim is neither radical nor as damaging to the Piagetian hard core as it initially appears. The related claim that social and cultural factors may have played a more significant role in the ontogenetic sequence discovered by Piaget is more challenging but still not a threat to the Piagetian hard core. It retains a commitment to equilibration as the fundamental factor in development and strengthens the programme's progressive theoretical and empirical shift by including the epistemic object in the process of construction. I will look at each of these issues in turn.

In his research on the development of geometry in the individual Piaget found that the individual sequence of development from topological to projective, and finally to Euclidean geometry completely inverts the historical sequence of Euclidean, projective to topological geometry (Kitchener, 1985). This "genetic paradox of geometry" clearly falsified the biogenetic law of recapitulation and presented a serious challenge to Piaget's hypothesis about the relationship between individual development and the history of science[16]. According to Kitchener (1985), Piaget failed to address this challenge adequately but would have attempted to explain it by appealing to social factors and the mechanism of reflective abstraction. Thus Piaget would contend that the individual sequence of development was "repressed or overridden" by social factors such as technology, the social and economic division of labour, etc., which he saw as largely responsible for the general historical transition from a lower level of knowledge to a level that is judged to be higher (Kitchener, 1985). Such factors would, however, be secondary to the more important psychogenetic factor of reflective abstraction in explaining the asymmetry between individual development and the history of science. Expanding on Claparède's Law of the grasp of consciousness (prise de conscience) which holds that

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[16] According to Kitchener (1985), the "genetic paradox of geometry" may explain Piaget's equivocation on the exact nature (i.e., correspondence, isomorphism, parallelism) of the relationship between individual development and the historical development of scientific thinking.

individuals are not generally aware of their mental operations but only of the results of such operations, and furthermore that individuals only become aware of their mental operations when they encounter obstacles to their thought, Piaget developed the notion of reflective abstraction[17]. According to this idea individuals are normally unaware of the underlying processes of their thinking (reflective abstractions) even though such processes do result in conscious, conceptual outcomes (reflected abstraction). The implication of this notion is that the historical emergence of scientific thinking (reflected abstraction) appears sooner than the underlying operations upon which it is based (reflective abstraction), or, as Piaget contends, "the order of reflection reverses that of construction" (Kitchener, 1985, p. 19). Thus, even though certain forms of knowledge are ontologically prior in their construction, the epistemological realisation of such knowledge occurs much later and this, according to Kitchener, could explain the "genetic paradox of geometry". By appealing to the notion that "the order of reflection reverses that of construction" the Piagetian research programme therefore anticipates (to some extent) the possibility of inversion postulated by Papert and renders it less damaging to the hard core.

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[17] This idea will be discussed in greater detail when we look at the LOGO programming language and the activities it intends to promote.

In contrast, Papert's particular formulation of the role of the epistemic object in the process of construction is more novel and opens up new possibilities of investigation for the Piagetian research programme. According to Papert (1980), the social, cultural and natural environment sets constraints and possibilities on the knowing subject's constructive activity and, concomitantly, determines the invariant sequence of epistemic stages of ontogenetic development discovered by Piaget. Specifically, he contends that in the construction of knowledge a subject necessarily uses the tactile, visual and kinaesthetic materials present in the total environment and that the constitution of these materials plays a definitive role in the type of knowledge which is constructed and the relative ages at which it is constructed. For example, the abundance of paired objects (e.g., knives and forks, cups and saucers, mothers and fathers, etc.) in the environment is a significant cultural "building block" in the child's early construction of one-to-one correspondences. Conversely, the relative paucity of cultural building blocks that can simplify and concretise operations such as seriation and conservation may play an equally important role in the later construction of these concepts. What this implies is that in Papert's view environmental materials are not merely a neutral given in the individual's constructive activity. Instead, they are an embodiment of socially constructed knowledge which 'activates' the grasp of consciousness/reflected

abstractions and 'shapes' the kinds of knowledge the individual constructs at various stages of her development[18].

On the basis of this shift from objects as a given to a conception of socially constructed epistemic objects on which the epistemic subject acts[19], Papert extends the theoretical problemshift of the Piagetian research programme in the following ways. First, he argues, the later development of formal operations is more a function of the availability of suitable building blocks which could simplify and concretise the formal than the inherent complexity of abstract thought as Piaget believed. Second, given the significance of cultural materials in the constructive process, Papert holds that the character of these materials plays a decisive role not only in determining the invariant sequence of the stages of development but also in the later construction of formal operations <u>within</u> a culture and the developmental time-lag that was found to exist <u>between</u>

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[18] Piaget accepts that objects are not a given but "immersed within a network of (social) relations" (Piaget & Garcia, p. 266). He does, however, hold that "the real meaning attributed to the object within the context of its interrelations with other objects may depend to a large extent on the way society acts upon the relations between the subject and object. But the way this interpretation is acquired depends on the subjects's cognitive mechanisms rather than on the contributions of the social group." (Piaget & Garcia, 1989, p. 267)

[19] Papert's reformulation of Piaget's dilemma here is clearly controversial. He thinks that <u>social</u> epistemic objects change the <u>form</u> of cognition and cognitive growth, which Piaget does not. However, I do not engage this dispute here: for purposes of my argument, I accept at face value the case that Papert makes.

cultures (see Dasen, 1972). Thirdly, insofar as culture and the socially constructed epistemic objects found within it set the constraints and possibilities on the types of knowledge that can be constructed and the ages at which they are constructed, significant social and cultural changes could shift the boundary between the concrete and the abstract and lead to the earlier development of formal operations and the development of new cognitive structures.

According to Papert (1980), the 'unorthodox' interpretation presented above opens up new possibilities for "applying" Piaget's genetic epistemology to education. Specifically, it provides a theoretical basis for addressing more concretely his particular concerns, viz., the learning and teaching of mathematics and the role that the newly constructed epistemic object, the computer, may play in this process. This concrete intervention proceeds from an analysis of existing conceptions and practices in mathematics education and establishes the framework in which Papert's vehicle for the learning of mathematics, viz., the LOGO programming language, should be understood.

Following Piaget's discoveries of the ontogenetic construction of number, Papert (1980) argues that the mathematics included in the existing school curriculum is at odds with our knowledge of the development of mathematics. That is, from both the historiogenetic and

psychogenetic perspectives, applied mathematics develops before pure mathematics but in the school curriculum pure maths is taught before applied maths, if at all. To facilitate the child's construction of mathematical knowledge it is therefore necessary to invert the current sequence by first demonstrating how mathematics works in concrete situations and to engage with its more abstract dimensions at a later stage. This reversal is, however, only a necessary condition for enhancing the learning of mathematics and is not sufficient: we also need to analyse the mathematics learning environment itself.

According to Papert, the mathematics learning environment of the school lacks the characteristics which contribute to the "success" of other forms of learning. In particular, compared to the success of early language learning which happens "naturally", "effortlessly", and "without conscious teaching", the learning of mathematics is fraught with difficulties and, despite the use of innovative teaching methods, largely unsuccessful. One reason for this differential success, in Papert's view, is that language is a constantly used and highly developed epistemic object which is firmly embedded in culture. Conversely, mathematics is relatively undeveloped, alienated from mainstream culture, and the preserve of a minority of people. Thus, to promote the learning of mathematics, it is also necessary to change existing social perceptions of the inherent complexity of mathematics, "re-insert" mathematics into mainstream

culture, and change its generally abstract nature by developing cultural materials that could simplify and concretise it.

In this regard the emergence of the general purpose computer and the computerisation of significant areas of human activity have not only initiated a process of dramatic social and cultural change, but have also presented us with an epistemic object that may be able to simplify and concretise mathematics. Therefore, the creation of this new epistemic object and the social and cultural changes that it has started will allow us to verify whether (a) the later development of formal operations is a function of the availability of adequate epistemic objects; (b) epistemic objects have a decisive influence on the invariant sequence of ontogenetic development and the developmental time-lag that exists between cultures; and (c) epistemic objects could shift the boundary between the concrete and the abstract. As such, these conditions could be seen as "a giant experiment in developmental psychology carried out on a social scale" (Papert, 1980d, p. 994).

The foregoing possibilities notwithstanding, mainstream uses of this new cultural material have not, as I have shown in the introduction, challenged existing ways of thinking about teaching and learning (mathematics). Instead, Papert (1980) is of the opinion that it is used as a new means of "force-feeding indigestible material

left over from the precomputer epoch" (p. 53). To counteract this reactionary tendency Papert (1988a) re-conceptualises the computer as "grist to the constructivist mill". In this capacity the computer becomes a means (a) to remove the obstacles to the child's constructive activity and to challenge entrenched conceptions of what children can learn and at which age; (b) to create genuinely novel learning environments which compensate for the deficiencies in existing learning environments and encourage the "natural" and "effortless" construction of "powerful ideas" without conscious teaching; (c) to foster the development of the child's meta-cognition; and (d) to facilitate the construction of new cognitive structures. However, while computers can be used "as grist to the constructivist mill", Papert (1980) cautions against the reductionist belief that computers by themselves would cause such cognitive changes. Instead he holds that it is only insofar as computers penetrate and transform culture in general that such changes could emerge. This process, he further believes, will ultimately depend on human choice and not on the computer.

From the foregoing analysis of the existing mathematics learning environment and his re-conceptualisation of the computer, Papert and his colleagues adopted the latest advances in computational science and AI research to create a new epistemic object that could simplify and concretise the learning of mathematics. The result of

their endeavours was the Turtle graphics microworld and the medium for communicating with this microworld, the LOGO programming language. Thus, to conclude my exposition of Papert's project I now need to look at the "applied" dimension of his genetic epistemology.

The Turtle Graphics Microworld and LOGO: Incubators for Powerful Ideas

The metaphor that Papert (1980) uses to describe the Turtle graphics microworld is that of a "mathland" in which children learn mathematics in the same way that a person living in France would learn French, i.e., naturally and without conscious teaching. The structure of this "mathland" is based on the idea of "microworlds" which was developed by AI researchers[20] and is intended to signify a limited domain of knowledge that can be simulated on a computer. The medium through which one communicates with this microworld is a pseudo-English, structured[21] computer programming language called LOGO

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[20] In their attempts to simulate cognitive processes on computers AI researchers encountered immense difficulties. Consequently, they restrict their focus to limited domains of cognitive activity, a microworld, which could be modelled on machines. Examples of microworlds are ELIZA, a program which simulates a Rogerian-type psychotherapist; PARRY, which simulates neurotic behaviour; and SHRDLU, a blocks-world program which is able to 'understand' and execute simple English instructions to arrange and re-arrange a number of differently shaped coloured blocks. For a more detailed discussion of these and other microworlds see Boden (1977).

[21] Early high level computer languages such as FORTRAN, COBOL and BASIC were unstructured and this resulted in what is called "spaghetti-type" programming, i.e.,

which, among other things, provides the user with the means to control the movements of a graphic, triangular-shaped "cybernetic animal", the Turtle, which is able to draw a continuous line as it moves.

Unlike the microworlds found in AI research which simulate pre-programmed and limited domains of cognitive activity, the Turtle graphics microworld is not a simulation of an event or an activity but a "conceptual system" (Pufall, 1988) or "conceptual space" (Fein, et al., 1988) which embodies a limited domain of mathematical knowledge, viz., computational geometry[22]. Very importantly, it is seen as similar to the 'real' world insofar as it contains elements for the construction of knowledge <u>without presenting them didactically</u> (Pufall, 1988). In particular, it contains elementary geometric principles such as lines, angles and vectors and is therefore a problem space restricted to spatial relations. Within this space there is a visually guided "object-to-think-with", the Turtle, which has both location and direction. In Papert's (1980) view this

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programming with no clear flow of control. To simplify the programming task structured languages such as PASCAL, LISP, C, and LOGO were developed. These languages require a more structured approach to problem-solving and programming.

[22] Although Papert does not state it explicitly one would assume that the use of computational geometry (which is different from Euclidian and more akin to topological geometry) as the entry point for learning mathematics via LOGO was consciously intended to 'fit in' with Piaget's discoveries of the construction of geometric knowledge discussed above.

object is akin to the plasticine and beads used in Piagetian experiments and easily assimilable to the child's sensori-motor knowledge. That is, there is a one-to-one relation between the Turtle's movements within the microworld and the child's movements in space and therefore she can think of the Turtle as a formal model of herself. So, by using her sensori-motor or, as Papert calls it, "body-syntonic" knowledge to negotiate space in the real world and translating her movements into LOGO commands that the Turtle should follow, the child can create an infinite variety of simple and complex geometric patterns.

In her actual interaction with the Turtle graphics microworld the child will engage in some or all of the following processes. First she is required to observe and understand the effects of primitive commands[23] (or words) on the Turtle's behaviour. After that she is encouraged to "teach the Turtle a new word". To do this she needs to combine some of the primitive commands according to definite syntactic rules and label her sequence of

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[23] Primitive commands are elementary structures (Piagetian schemes?) which have been pre-programmed in the LOGO language. These include, among others, the commands FORWARD (FD), BACK (BK), LEFT (LT), and RIGHT (RT) which in conjunction with some input parameter (e.g., 50) will cause the turtle to move as specified. For example, FD 50 will cause the Turtle to move 50 "Turtle steps" in the direction it is currently facing and if the command PENDOWN (PD) was previously issued, it will draw a continuous line as it moves. Similarly, the command RT 90 will cause the Turtle to rotate right on its axis to face a direction which is at a 90 degree angle to its previous orientation.

commands (or procedure) with a unique name. Very often, however, the Turtle does not produce the child's intended result and when this happens she is introduced to the "powerful idea" of "debugging"[24]. The actual process of debugging entails the use of the metaphor "play Turtle". Following this metaphor the child is required to "walk through" the sequence of commands or procedure issued to the Turtle, isolate logical and/or syntactical errors or "bugs" in the procedure by consciously reflecting on her bodily movements, and, on the basis of the insights gained from such reflections, to "fix" or "debug" her procedure. Once the errors have been eliminated and the desired result is achieved the procedure is labelled[25] with a unique name or identifier and stored for use with the primitive commands and/or previously stored procedures. In this way the child extends LOGO's 'vocabulary' and, concomitantly, the range of objects that may be used to complete more complex projects.

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[24] This idea has a numbe of implications for educational practice in general. It attempts to break the common sense assumption that learning is about "getting it" and intends to cultivate a disposition towards learning which is predicated on whether unintended/incorrect outcomes can be "fixed" rather than the view that learning is about "getting it right the first time". Equally importantly it attempts to encourage a more positive attitude towards the making of errors as a necessary aspect of the construction of knowledge (cf. Piaget's views on the importance of "false theories" in the development of knowledge).

[25] The naming of a procedure is always the first step and not, as my description suggests, the last. My intention here is only to clarify the nature of the activity and is not intended as a description of the actual activity.

Although LOGO permits the use of single commands to communicate with the Turtle in direct mode[26] the structure of the language favours a more systematic approach to programming and problem-solving. This feature of the language has been responsible for some of the major controversies in the LOGO research literature and it is therefore necessary to look more closely at the activities in the LOGO environment.

Like other structured languages LOGO embodies a number of characteristics such as proceduralisation and hierarchisation which, from the perspective of computer science, are important for facilitating the use of Polya's (1945/1990) problem-solving heuristics. These heuristics, the computer scientists believe, encourage a more structured approach to problem-solving and lead to more efficient and effective computer programming practices. When applied to the LOGO environment this orientation to computer programming leads to some or all of the following activities: to complete a project successfully and efficiently the child should (a) understand the problem involved; (b) divide it into manageable sub-problems; (c) analyse and solve each sub-problem as an entity in itself; (d) name and code the

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[26] In the "direct mode" the user issues a command which is immediately executed. In the "indirect mode" a procedure is named, constructed and stored using the LOGO editor and is only executed when 'called'. The disadvantage of the direct mode is that the series of single commands is not recoverable after execution whereas named procedures become part of the LOGO vocabulary to be used and edited in accordance with the demands of a particular task.

solved sub-problems as self-contained procedures using the LOGO primitives and/or previously stored procedures (if any); (e) debug the coded procedures individually by "playing Turtle"; (f) combine the various debugged procedures to form larger, self-contained modules if necessary; (g) arrange and integrate the various modules to complete the program; (h) execute the completed program to verify whether the intended objectives have been achieved; and finally, (i) debug and correct any existing errors of logic and/or syntax.

The foregoing process is obviously very efficient from the perspective of computer science but it is quite contrary to the constructivist spirit of the Turtle graphics microworld and the LOGO philosophy in general. However, it is exactly because of their belief in the former and the neglect of the latter that LOGO researchers have attempted to verify whether the use of LOGO would enhance this type of structured problem-solving in children. Also, where this outcome has not been achieved, these researchers have felt that it is necessary to teach these problem-solving heuristics more explicitly. In Papert's view the Turtle graphics microworld and the LOGO programming language are only "incubators for powerful ideas" and therefore both of the foregoing endeavours miss the point. First, he argues that these problem-solving heuristics are only a contingent and not a necessary outcome of using LOGO. Secondly, he opposes the formal teaching of these

heuristics as the way to interact with the Turtle graphics microworld because that would be tantamount to what Weizenbaum (1984) calls "the imperialism of instrumental reason". What is important for Papert is the child's constructive activity itself and the mathematical[27] knowledge which she constructs by interacting with the elements embodied in the Turtle graphics microworld (see Pufall, 1988; Fein, et al., 1988). Thus, to understand the child's activity in the LOGO environment we need to look briefly at Piaget's conception of the role of activity or action in the construction of knowledge.

Implicit in the LOGO researchers' belief that the logical structure of LOGO will necessarily produce certain logical outcomes, is the empiricist assumption that knowledge is derived from experience in a simplistic and uni-directional manner. In opposition to this "myth of the sensory origin of knowledge" (Piaget, 1972) which sees endogenous knowledge as a simple internalisation of exogenous knowledge (Piaget, 1975), Piaget (1983) argues that

> in order to know objects the subject must act upon them: he must displace, connect, combine, take apart, and reassemble them . . . From the

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[27] Most LOGO researchers tend to concentrate on the development of specific programming skills rather than the construction of mathematical knowledge. Although such skills are important they are, in Papert's understanding, secondary to the construction of mathematical knowledge. In this regard these researchers have again "missed the point".

> most elementary sensorimotor actions (such as pushing and pulling) to the most sophisticated intellectual operations, which are interiorized actions, carried out mentally (e.g., joining together, putting in order, putting into one-to-one correspondence), knowledge is constantly linked to actions or operations, that is, with transformations. (p. 104, emphasis in the original)

Following from the importance of physical and mental activity or action in the construction of knowledge the important issue for Piaget is therefore to explain how physical actions are internalised and co-ordinated into operatory structures (i.e., groups and lattices) which can be applied to any objects, or which can function without any objects (as in pure mathematics). According to Piaget (1976), the process of internalisation consists of a series of co-ordinations of actions which are constituted on three levels. The practical or sensori-motor co-ordinations constitute Level I while the conceptual co-ordinations make up Levels II and III. The three levels of co-ordination are interdependent insofar as Level II uses some of the component actions of Level I, while Level III relies on the co-ordinations of Levels I and II. Seen as a continuous process, Level I is the level on which the subject acts on objects by combining them, taking them apart, and re-assembling them. At Level II these material actions are internalised through two types of abstraction, empirical abstraction and reflective or reflexive abstraction, to become "meaning-bearing representations" (Piaget, 1976, p. 351). Empirical abstraction provides the subject with

descriptive ideas of the overt features of the material actions of Level I, while reflexive abstraction uses the information obtained from the co-ordinations of material actions to make "inferential co-ordinations", i.e., new connections between actions which go beyond the observable characteristics of those actions. These inferential co-ordinations include additive co-ordinations (where actions are joined), sequential or ordinal co-ordinations (where actions succeed each other in a temporal sequence), one-to-one correspondence co-ordinations (where a correspondence between actions is established), and lastly, co-ordinations which establish intersections between actions. All of these co-ordinations, according to Piaget (1976), have parallels in formal logic and therefore form the basis of the development of logical thought structures in the individual.

Initially, according to Piaget, the individual is unaware of the processes of empirical and reflexive abstraction and it is only when she begins to reflect on her thinking that she reaches Level III. At this level she becomes conscious of the products of her reflexive abstractions, i.e., reflected abstractions, and is then able to theorise about the nature of the external world. Thus, by using the interdependent processes of empirical and reflexive abstraction, the individual constructs both physical and logico-mathematical knowledge (see Gallagher, 1978; Kamii & de Vries, 1978; Kamii, 1985).

However, within the latter process we also need to take account of what Piaget (1975) calls the Alpha, Beta and Gamma compensatory structures (see Rowell, 1989).

According to Piaget (1975) when an individual is confronted with novel objects, events or exogenous knowledge which disturbs her equilibrium, her initial response will be an attempt to neutralise the disturbance by ignoring it or deforming it so that it is no longer experienced as a disturbance. This tendency to resist change is called Alpha compensations. The equilibrium which is established through this compensation is only partial and unstable and insufficient to prevent further disturbances. Eventually, therefore, the Alpha compensations are superseded by Beta compensations in which the individual eliminates the disturbance by integrating it as a new variation into her existing knowledge. The reconstructions of the Beta phase are finally completed by the Gamma compensations to become a system of reversible operations which is able to accommodate the original disturbance and anticipate similar disturbances in the future.

The implications of the foregoing conception of the nature of activity (and its related compensations) for understanding children's activity in the LOGO environment are numerous and open up a host of possibilities for future research. Proceeding from the premise that exogenous knowledge is <u>reconstructed</u> endogenously, we

could use the positive heuristic of the Piagetian research programme, viz., the clinical method, to examine the various abstractions in the context of the Turtle graphics microworld and attempt to explain the particular kinds of knowledge that individual users construct, or, we could look at the various compensations and the gradual re-organisation of existing knowledge, and so on. In this way we could begin to understand how a newer epistemic object constrains or facilitates the construction of knowledge on a psychogenetic level (e.g., its effects on the stages of development and the boundary shift, if any, between the concrete and the abstract) which in turn may have implications for understanding the historiogenetic development of scientific thinking.

Unfortunately, except for the research conducted by Papert, et al. (1979); Watt (1979); Lawler (1981; 1985); Lawler, et al. (1986); Turkle (1984); the contributors to Forman & Pufall (1988) and Harel & Papert (1991); and Turkle & Papert (1991), the foregoing ideas are virtually absent from the LOGO research literature. Instead, what most LOGO researchers have looked at is what the negative heuristic of the Piagetian research programme would consider to be the "epistemologically trivial" dimensions of the process of learning while using a research methodology, viz., the experimental research method, which is unable to elucidate the underlying mechanisms, structures and functions that the process of learning entails. Thus, in complete agreement with Papert I would

contend that these researchers have indeed "missed the point".

Conclusion

As an attempt to intervene on a theoretical level in the "controversy and paradox" surrounding the LOGO research literature, I have presented what I consider to be a more consistent 'reading' of Seymour Papert's theory and research. In particular, I have taken his characterisation of his work as "an exercise in an applied genetic epistemology" as the most appropriate starting point for defending his assertion that the majority of the LOGO researchers have "missed the point". Consonant with this conception of his work as fundamentally epistemological, albeit an "applied" epistemology, my exposition of Papert's theory and research focused consistently on its epistemological premises and the conclusions for practice that he derives from these premises. In this regard I showed that Papert's epistemology can only be understood in the context of Piaget's genetic epistemology and argued that his overall project should be located within the Piagetian research programme. From this perspective, I further argued, his work can be seen as making a significant contribution to the progressive theoretical problemshift of the programme through its theorisation of the role of socially constructed epistemic objects in the development of cognition, as well as increasing the empirical content of the programme through its research on children's activity with such objects. Lastly, to complete my discussion of Papert's project I looked at

its "applied" dimension, viz., the Turtle graphics microworld/LOGO language and the "epistemologically significant" aspects of children's activity with these epistemic objects. With regard to the former I showed that Papert's epistemic objects have been misrepresented as didactically presenting information rather than embodying elements for the construction of mathematical knowledge. This misrepresentation, I further argued, is based on an empiricist conception of learning which leads to an "epistemologically trivial" construal of children's activity with these objects. Consequently, I would contend, there is an essential incompatibility between Papert's constructivist framework and the empiricist frameworks of his critics and detractors. To demonstrate this incompatibility I want to return to the questions posed in the introduction of this research report.

- What are the cognitive benefits (if any) of using LOGO and are these purported benefits supported by Papert's writings?

From my presentation I believe it is clear that the cognitive benefits which are assumed to result from children's interaction with the LOGO learning environment are predicated on an empiricist conception of learning and are therefore not consistent with Papert's constructivism. So, while it cannot be denied that Papert does posit the possibility of certain cognitive outcomes as a function of using computers and LOGO, these outcomes

are not seen as necessary. The possibility of specific outcomes being attained is, according to Papert, open-ended and, very importantly, dependent on significant social and cultural changes in which newer, socially constructed epistemic objects such as computers have become pervasive. Insofar as these changes have not yet been realised it becomes extremely difficult (if not impossible) to verify empirically the veracity of these predictions at the present time. The belief that a sound research methodology which "maximises falsifiability" would show more clearly the presence or absence of such cognitive outcomes is therefore equally misguided. Thus, the claim that LOGO "promised more than it has delivered" cannot be sustained and in this regard has "missed the point".

- Is Papert justified in his assertion that (most) LOGO researchers have "missed the point"?

Following Papert's claim about the essentially epistemological nature of his work, the assertion that LOGO researchers have "missed the point" is justified on a number of levels. First, as I have shown, LOGO researchers tend to treat Papert's work as an exclusively psychological and educational enterprise and in the process ignore the epistemological assumptions on which it is based. Secondly, where these researchers have taken cognizance of the Piagetian basis of his thinking they have assimilated his work into a prior, empiricist

understanding of Piaget and consequently missed the fundamentally constructivist nature of his work. Thirdly, in their failure to acknowledge the epistemological dimension of his work, these researchers have been unable to see the continuities and discontinuities between Papert and Piaget and the relationship between Papert and the Piagetian research programme. In this regard they missed the point that Papert's claims about computers and LOGO are auxiliary hypotheses which increase the theoretical and empirical shift of the programme. As such, I contend, these claims only become sensible in the context of the Piagetian research programme. By ignoring all of these epistemological dimensions of Papert's work and treating it as a variant of CAI, these researchers have therefore "missed the point".

- What is the point of the LOGO enterprise?

On the basis of my exposition of Papert's "exercise in an applied genetic epistemology", and my argument that this exercise should be seen as one of the theories that make up the Piagetian research programme, I believe that the LOGO enterprise has two important dimensions. The first is epistemological and the second is practical. With regard to the epistemological dimension I believe that I have adequately demonstrated Papert's 'extension' of Piagetian theory to include the role of epistemic objects in the development of cognition. This extension, I believe, generates a number of interesting hypotheses

concerning (a) the role of epistemic objects in establishing the invariant sequence of stages of development discovered by Piaget; (b) the possibility of the 'inversion' of this sequence of stages as a function of significant social and cultural change and the concomitant changes in the nature of a society's epistemic objects; and (c) the inherent complexity of formal operational thinking and whether such thinking could occur at earlier ages if adequate epistemic objects are available. On a general level the 'confirmation' of these hypotheses could elucidate some of the difficulties in genetic epistemology such as the complex relationship between historiogenesis and psychogenesis, and the issue of the necessity of the stages of development, among others.

The practical dimension of the LOGO enterprise is well known, but is, as I have tried to show, misrepresented as a variant of CAI. Conceptualised as an epistemic object that embodies elements for the construction of mathematical knowledge (rather than as a medium for teaching computer programming) it establishes a new context within which the various abstractions and compensatory structures can operate. Furthermore, as an epistemic object which was consciously developed to concretise the abstract, it opens up the possibility of shifting the boundary between the concrete and the abstract which in turn could lead to the earlier development of formal operations in the child. However,

as Papert has consistently argued, it would be reductionist to see LOGO as necessarily producing these outcomes. Ultimately, it is only to the extent that LOGO and computers penetrate and transform culture in general and the learning environment in particular that these cognitive 'effects' may occur.

What all of the foregoing suggests is that there is an essential incompatibility between Papert and the majority of the LOGO researchers. This incompatibility, I would argue, has been responsible for the "controversy and paradox" surrounding the LOGO enterprise. Thus, to break the deadlock that these controversies have produced, I believe that future researchers should take greater cognizance of the essentially epistemological and constructivist nature of Papert's work and its relation to the Piagetian research programme, because it is only in this framework that his particular claims for computers and LOGO can be evaluated. Also, as I have shown above, this framework is rich with possibilities for future empirical research which may contribute to our understanding of the role of epistemic objects in the construction of knowledge as well as elucidating the relationship between historiogenesis and psychogenesis. To do otherwise would be to "miss the point".

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