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AUTHOR Niaz, Mansoor

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ABSTRACT

This paper helps to clarify the role of empirical evidence in psychological and epistemological theories. Following Galileo's idealization, epistemological theories do not describe the behavior of individuals in the real world. It is only when the "impediments" of the real subjects are gradually removed by experimental manipulation that the real performance of individuals can approximate the competence of the ideal epistemic subject. It is concluded that Galileo's method of idealization has important implications for the construction of the neo-Piagetian epistemological theory. Discussed are Galileo's method of experimental analysis, the role of the epistemic subject in Paiget's genetic epistemology, the relationship between Galileo's ideal laws and Piaget's ideal knower, and the manipulation of the impediment variables. (KR)

FROM GALILEO TO PIAGET: HOW DO WE CONSTRUCT EPISTEMOLOGICAL THEORIES?

MANSOOR NIAZ

CHEMISTRY DEPARTMENT, UNIVERSIDAD DE ORIENTE

APARTADO POSTAL 90, CUMANA, ESTADO SUCRE, VENEZUELA

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ABSTRACT

There are three main problems in the empirical testability of Piaget's theory: 1) the underdetermination of scientific theory by empirical data; 2) the problematic nature of Piaget's competence-level explanations; and 3) the vexing issue of how an epistemological theory can even be testable by ordinary empirical evidence. An analogy to Galileo's methodology is illuminating because psychologists and science educators have widely thought they should emulate physics, which is the paradigm-case of science, and because a study of Galilean methodology reveals its non-empirical nature. In order to 'prove' his law of free fall Galileo should have presented empirical evidence to his contemporaries. As a direct empirical test of Galileo's ideal law was not possible, he asked an epistemological question, and designed his famous inclined plane experiment to show that as the angle of incidence approximated 90^o (free fall) the acceleration of objects rolling down an inclined plane increasingly approximated a constant. According to Galilean methodology, after having asked the right question, a scientist could experimentally vary one impediment (e.g., air resistence) along a range of values approaching zero. One then observes what happens to the dependent variable (e.g., free fall). Following Galileo's idealization, scientific laws being epistemological constructions do not describe the behavior of actual bodies.

It is plausible to suggest that just as Galileo's ideal law can be observed only when all the impediment variables approach zero, similarly individuals in the real world have various 'impediments' and it is only when these impediments are gradually removed by experimental manipulation that the real performance of individuals can approximate the competence of Piaget's epistemic subject (ideal knower).

Finally, evidence is presented to the effect that by experimentally manipulating the impediment variables (e.g., Pascual-Leone's M-demand and Witkin's perceptual field effect of a task), performance of the real subjects approximates the competence of the ideal epistemic subject, which leads to the construction of a neo-Piagetian epistemological theory.

I. Galileo's Method of Experimental Analysis

According to Hanson (1958): "Why does motion cease? That was Galileo's problem" (p. 41). In contrast to Aristotle, who believed that a continually acting cause (i.e., force) was necessary to keep a body moving horizontally at a uniform velocity, Galileo predicted that if a perfectly round and smooth ball was rolled along a perfectly smooth horizontal endless plane there would be nothing to stop the ball (assuming no air resistence), and so it would roll on forever. Galileo, however, did not have the means to demonstrate that Aristotle was wrong, so he asked an epistemological question: What would make it (body) stop? Similarly, Galileo's discovery of the law of free fall, later led to a general constructive model of falling bodies (Pascual-Leone, 1978). The law in its modern form can be represented by: $s = 1/2\ g\ t^2$ (s = distance, t = time, and g = a constant). In order to 'prove' his law of free fall, Galileo should have presented empirical evidence to his contemporaries by demonstrating that bodies of different weight (but of the same material) fall at the same rate. If the leaning tower of Pisa mythical experiment was ever conducted, it would have shown Galileo to be wrong. According to Pascual-Leone (1978a), empirical computation of the value of s as a function of the variable t, "... where vacuum and other simplifying assumptions are not satisfied" (emphasis added, p. 28), would lead to a rejection of the law. As a direct empirical test of Galileo's ideal law was not possible, he used his famous inclined plane experiment to show that as the angle of incidence approximated 90° (free fall), the acceleration of objects rolling down an inclined plane increasingly approximated a constant. According to Kitchener (1990), "... by extrapolation one may assume it is also true of free fall as a limiting case" (p. 13). Following the Galilean methodology, after having asked the right question, according to Kitchener (1990): "A scientist must experimentally vary one impediment (e.g., air resistence) along a range of values approaching zero. One then observes what happens to one's dependent variable (e.g., free fall). If, as the value of the impediment variable approaches zero, the value of the dependent variable approaches one's ideal law, one is justified in assuming that, if the impediment variable were zero, then the dependent variable would approach the ideal law as a limiting case" (pp. 13-14). Galileo's idealization, by which he separates the ideal or scientific object of knowledge from real objects, is considered to be the defining characteristic of modern non-Aristotelian science (Matthews, 1987).

II. Role of the Epistemic Subject in Piaget's Genetic Epistemology

Piaget's genetic epistemology distinguishes between the epistemic and the psychological subjects.

> "... a fundamental epistemological distinction must be introduced between two kinds of subjects or between two levels of depth in any subject. There is the 'psychological subject', centered 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" (Beth and Piaget, 1966; p. 308).

The epistemic subject being an abstract, ideal knower is not to be identified with real individuals, although real individuals under ideal conditions can approximate this epistemic subject to varying degrees. According to Kitchener

(1990): "What is unique about the epistemic subject is the fact that it is epistemic, i.e., the epistemic subject is the knower (not just the thinker)" (p. 9), and nor is the epistemic subject the average behavior of a group of real individuals (Kitchener, 1986). It is essential to point out that following Galileo's method of idealization, scientific laws being epistemological constructions do not bescribe the behavior of actual bodies. "The gas laws, inheritance laws, Newton's laws, Piagetian stages etc. -- all of these describe the behavior of ideal bodies, they are abstractions from the evidence of experience. The laws are true only when a considerable number of disturbing factors (itemised in the caeteris paribus clauses) are eliminated.... The art of experimentation is to progressively try to do so" (Matthews, 1987, p. 295). Niaz (1991) has shown that the failure to understand the distinction between the epistemic and the psychological subjects would be to misconstrue the significance of our research findings in science education, and what is more serious lead to a lack of a historical perspective.

III. Relationship between Galileo's Ideal Laws and Piaget's Ideal Knower

It is plausible to suggest that the role of the epistemic subject (ideal knower) in Piaget's genetic epistemology is similar to that of Galileo's ideal laws in the study of motion (Kitchener, 1990). Just as Galileo's ideal law can be observed only when all the impediment variables approach zero, similarly individuals in the real world have various 'impediments' and it is only when these impediments are gradually removed by experimental manipulation that the real performance of individuals can approximate the competence of the ideal knower.

IV. Manipulation of the Impediment Variables: Towards a neo-Piagetian Epistemological Theory

Piaget's genetic epistemology has focussed on: How is the development of knowledge (competence) possible. In order to achieve this Piaget has utilized the 'methodology of simplifying assumptions' (cf. Galileo's idealization) by ignoring impediment variables, such as, "... cognitive styles, studies of variables that detract from correct reasoning, attention, and memory limitations" (Kitchener, 1986; p. 28). According to Pascual-Leone (1987) the transition from the 'General Model' (i.e., Piaget's epistemic subject) to the 'Situation-Specific Model (i.e., Piaget's psychological subject) must be explained by functional constraints (impediment variables), and helps to differentiate between constructivist-rationalist and empirical theories. To put it in a historical perspective, Piaget builds a 'General Model' by neglecting the impediment variables, i.e., studies the epistemic subject, whereas Pascual-Leone by incorporating a framework for impediment variables studies the metasubject, i.e., the psychological organization of the epistemic subject, which is an attempt at explaining performance or specifying process criteria. Pascual-Leone considers his Theory of Constructive Operators (TCO) to be a, "... model of the psychological organism (the metasubject) which is at work inside Piaget's 'epistemic subject' for each age group as much as inside the particular children which educators encounter" (Pascual-Leone, Goodman, Ammon, & Subelman, 1978; p. 271). Niaz (1990) has demonstrated that antecedent variables based on Pascual-Leone's TCO provide greater explanatory power for cognitive development and science achievement, and this can be interpreted (cf. Niaz, 1991a) as an epistemic transition between Piaget's epistemic subject and Pascual-Leone's metasubject.

By taking our clue from Galileo, in this section we provide evidence to the effect that by experimentally manipulating the impediment variables (M-demand and perceptual field effect of a task) performance of the real subjects approximates the competence of the ideal epistemic subject.

a) Manipulation of M-demand of a task and its effect on student performance.

Niaz and Lawson (1985) have studied student performance in balancing chemical equations (presented below) as a function of the following predictor variables: Piaget's formal operational reasoning and Pascual-Leone's M-capacity, i.e., the ability of the subject to process information.

Equation 1: $2H_2XO_3 + H_3ZO_3 \longrightarrow HX + H_3ZO_4 + H_2O$

Equation 2: $H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + H_2O$

In view of the fact that the TCO (Pascual-Leone, et al., 1978) emphasizes the importance of a 'trade-off' between the subject's M-capacity and the M-demand (Maximum number of steps/schemes that the subject must mobilize/activate simultaneously) of the task, equation 1 was estimated to have an M-demand of 5 or more and equation 2, an M-demand of 1. Results obtained are summarized below:

1) Performance of formal operational students increased from 33% on equation 1 (M-demand = 5 or more) to 100% on equation 2 (M-demand = 1).

2) Pearson correlation coefficients of 0.63 ($p < 0.01$) and 0.68 ($p < 0.01$) were obtained between the Lawson (1978) test of formal reasoning and the balancing of chemical equations 1 and 2, respectively.

3) Pearson correlation coefficients of 0.60 ($p < 0.01$) and 0.06 were obtained between a test of M-capacity and the the balancing of equations 1 and 2, respectively.

4) Multiple regression analysis showed a multiple R of 0.57 among the predictor variables and performance on equation 1. M-capacity and formal reasoning

explained 23% ($F = 6.74$, $p < 0.05$) and 10% ($F = 5.13$, $p < 0.05$) of the variance, respectively.

5) Similarly, a multiple R of 0.51 was obtained among the predictor variables and performance on equation 2. M-capacity and formal reasoning explained 1% and 25% ($F = 7.22$, $p < 0.05$) of the variance, respectively.

How do we interpret these results? Both equations require formal operational reasoning, that is, an indicator of the epistemic subject's competence, and this is an example of what Piaget's structural theory accomplishes. Piaget's theory, however, does not explain why do the students perform poorly on equation 1. It is important to note that the amount of variance explained by M-capacity increases from 1% in equation 2 (M-demand = 1) to 23% in equation 1 (M-demand = 5 or more), an indicator of a functional constraint (impediment) in student performance, that is, an explication of Pascual-Leone's metasubject. Finally, if we consider the M-demand of the equations as an impediment, it can be observed that as the impediment decreases, the performance of students who are formal operational increases from 33% on equation 1 to 100% on equation 2. Similarly, Scardamalia (1977) has shown that by manipulating the M-demand of combinatorial reasoning tasks even eight year olds can succeed. Further evidence is provided by Niaz (1988, 1989a).

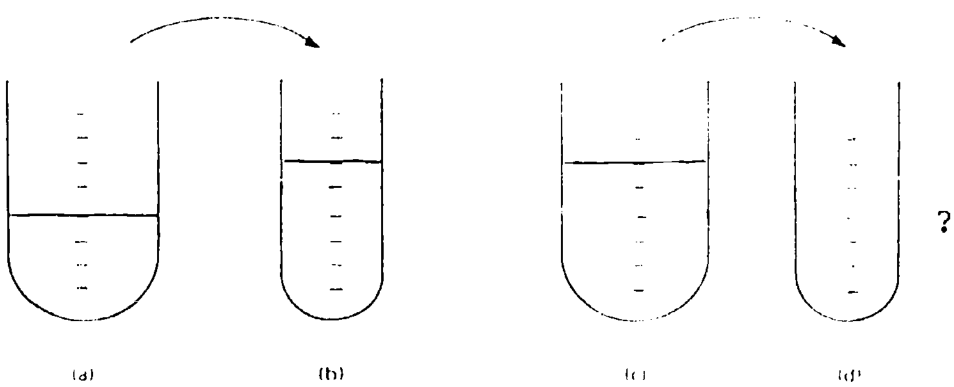
b) Manipulation of the perceptual field factor and its effect on student performance

Most Piagetian tasks present misleading situations (cf. Pascual-Leone, 1976) because they elicit powerful error factors that produce erroneous strategies. According to Pascual-Leone two of the most common types of error factors are: 1) Overlearned, LC (L = Logical learning and C = Content learning) schemes or structures developed in other situations where they were relevant, which are irrelevantly elicited in the new situation by salient yet misleading cues; and 2) Organismic disposition to produce performance which is congruent with the dominant features of the field-activated figurative (i.e., the perceptual field factor) schemes. As an illustration of the perceptual field factor consider the Water Pouring Task (Lawson, 1978), which requires proportional reasoning:

Water Pouring Task: Water was poured in a wide cylinder up to the fourth mark (see figure a). This water was transferred into the narrow cylinder and water rose up to the sixth mark (see figure b). Now if water is poured into the wide cylinder up to the sixth mark (see figure c):

Question: How high would this water rise if it were poured into the narrow cylinder (see figure d)?

Answer: The water will rise to mark: (a) 7; (b) 8; (c) 9; (d) 10; (e) other; (f) there is no way of predicting.



Results obtained (cf Niaz, 1989b) show that out of a sample of 318 freshman students 179 were classified as field-dependent (cf. Witkin, et al., 1971) and of these 144 (80%) responded: water level 8. It is plausible to suggest that the dominant figurative feature (4 ---> 6 ∴ 6 ---> X) of this task conduces the field dependent subjects to use an ADDITIVE strategy and respond, water level 8. In a subsequent study Niaz (1988a) has reported the effect of manipulation of the field factor on subject performance in the Water Pouring Task. Essentially the task remains the same, except for the instruction that the water from the wide cylinder at the third mark rises to the fifth mark when poured into the narrow cylinder. Students are asked to predict how high water at the fourth mark in the wide cylinder will rise when poured into the narrow cylinder. As can be observed the perceptual field effect would change to: $3 \longrightarrow 5 \therefore 4 \longrightarrow X$. Considering the fact that the M-demand and the formal operational reasoning pattern of the task remain constant any change in subject performance can be attributed to the manipulation of the perceptual field factor. Results obtained show that of a sample of 113 freshman students 48 were classified as field-dependent and of these 32 (67%) responded: water level 6 (i.e., the additive strategy). These results show that as the impediment (perceptual field factor) decreases, student performance on the Water Pouring Task improves.

V. Conclusion

This paper helps to clarify the role of empirical evidence in psychological and epistemological theories. Following Galileo's idealization, epistemological theories do not describe the behavior of individuals in the real world. It is only when the 'impediments' of the real subjects are gradually removed by experimental manipulation that the real performance of individuals can approximate the competence of the ideal epistemic subject. It is concluded that Galileo's method of idealization has important implications for the construction of the neo-Piagetian epistemological theory.

REFERENCES

Beth, E.W., & Piaget, J. (1966). Mathematical Epistemology and Psychology (trans. W. Mays), Dordrecht: Reidel.

Hanson, N.R. (1958). Patterns of Discovery. Cambridge: Cambridge University Press.

Kitchener, R.F. (1986). Piaget's theory of Knowledge: Genetic Epistemology and Scientific Reason. New Haven: Yale University Press.

Kitchener, R.F. (1990). Piaget's epistemic subject and science education: Epistemological vs. psychological issues. Paper presented at the 63 Annual Conference of the National Association for Research in Science Teaching, Atlanta,April.

Lawson, A.E. (1978). The development and validation of a classroom test of formal reasoning. Journal of Research in Science Teaching, 15, 11-24.

Matthews, M.R. (1987). Experiment as the objectification of theory: Galileo's revolution. Proceedings of the Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, 1, 289-298, Ithaca,NY: Cornell University.

Niaz, M. (1988). Manipulation of M-demand of chemistry problems and its effect on student performance: A neo-Piagetian study. Journal of research in Science Teaching, 25, 643-657.

Niaz, M. (1988a). Student performance in water pouring and balance beam tasks: Effect of manipulation of perceptual field factor. Research in Science and Technological Education, 6, 39-50.

Niaz, M. (1989a). Dimensional analysis: A neo-Piagetian evaluation of M-demand of chemistry problems. Research in Science and Technological Education, 7, 153-170.

Niaz, M. (1989b). The role of cognitive style and its influence on proportional reasoning. Journal of Research in Science Teaching, 26, 221-235.

Niaz, M. (1990). Does Newton's falling apple require an explanation? Antecedent variables in cognitive development: Controversy and resolution. Perceptual and Motor Skills, 70, 755-758.

Niaz, M. (1991). Role of the epistemic subject in Piaget's genetic epistemology and its importance for science education. Journal of Research in Science Teaching, (in press).

Niaz, M. (1991a). From Piaget's epistemic subject to Pascual-Leone's metasubject: Epistemic transition in the constructivist-rationalist theory of cognitive development. Manuscript submitted.

Niaz, M., & Lawson, A. E. (1985). Balancing chemical equations: The role of developmental level and mental capacity. Journal of Research in Science Teaching, 22, 41-51.

Niaz, M., & Robinson, W. R. (1991). Manipulation of logical structure of chemistry problems and its effect on student performance. Journal of Research in Science Teaching, (in press).

Pascual-Leone, J. (1976). On learning and development, Piagetian style: I. A reply to Lefebvre-Pinard. Canadian Psychological Review, 17, 270-288.

Pascual-Leone, J. (1978). Piaget's two main stage criteria: A selective reply to Brainerd. Behavioral and Brain Sciences, 2, 200-201.

Pascual-Leone, J. (1978a). Compounds, confounds, and models in developmental information processing: A reply to Trabasso and Foellinger. Journal of Experimental Child Psychology, 26, 18-40.

Pascual-Leone, J. (1987). Organismic processes for neo-Piagetian theories: A dialectical causal account of cognitive development. International Journal of Psychology, 22, 531-570.

Pascual-Leone, J., Goodman, D., Ammon, P., & Subelman, I. (1978). Piagetian theory and neo-Piagetian analysis as psychological guides in education. In J. M. Gallagher & J. A. Easley (Eds.), Knowledge and Development. New York: Plenum. Pp. 243-389.

Scardamalia, M. (1977). Information processing capacity and the problem of horizontal decalage: A demonstration using combinatorial reasoning tasks. Child Development, 48, 28-37.

Witkin, H.A., Oltman, P.K., Raskin, E., & Karp, S.A. (1971). A manual for the embedded figures test. Palo Alto, CA: Consulting Psychologists Press.