9 K. Sheingold, J. H. Kane, and M. E. Endreweit, "Microcomputer Use in Schools: Developing a Research Agenda," *Harvard Educational Review* 53, no. 4 (1983): 412-32.

10 Equity issues in relation to socioeconomic level involve two basic factors: the availability of computers in a school, and the types of activities for which the computers are used—programming and/or computer-assisted instruction. The former involves financing, the latter the kind of learning opportunities to be offered to students. Further refinement of these issues is presented in the Center for Social Organization of Schools report, The Johns Hopkins University (vol. 1, no. 1, November 1983, 15 pp.). For example: "Predominantly minority elementary schools use drill-and-practice activities much more than they use programming activities with their students. In contrast, low SES predominantly white elementary schools teach programming to students more often than they use micros for drill work, even more, for example, than the high SES elementary schools do" (p. 4). Also see H. J. Becker, "Microcomputers in the Classroom: Dreams and Realities," Center for Social Organization of Schools, The Johns Hopkins University, Report no. 319 (March 1982, 76 pp.). Concern over the possibility that computer use will be predominantly a boys' activity has caused educators to think about the concerted effort needed to support and encourage the interest of girls in computers. Such affirmative action would complement similar work being done in the area of mathematics with girls. There is a company that has developed and is marketing computer materials for girls—RHIANNON/Computer Games for Girls. As their promotional material states, the games in their first series are "related to essential survival in various historical and geographical settings." Emphasis is on "integrated styles of thinking rather than the repetitive point acquisition of most computer games."

11 If only in passing, concern has been expressed over the influence of business interests on educational decisions—to what degree will the available hardware and software determine curriculum content? Obviously, school purchasing will be a market to court on the part of manufacturers, just as publishing contracts have been. News items such as the following concretize some of the questions being raised: "Atari and General Foods' Post Cereals recently launched a nationwide, multi-million dollar computer literacy program called 'Catch on to Computers.' [It is] designed to give all age groups a free hands on learning experience with computers. . . . The Catch on to Computers events are part of a national program offering computer hardware and software in exchange for proof-of-purchase seals from any brand of the entire line of Post Cereal brand." (*Electronic Education* 3, no. 2 [October 1983]: 55).

12 The health issues that have been raised still seem to be in the realm of possibility. Concern has been expressed, both in the popular press and professional journals, regarding possible physiological consequences of microcomputer use. The areas most commonly mentioned are eye and musculoskeletal difficulties and neurological implications. Considering the amount of time that might be spent with computers from the time of schooling through one's career, coupled with television viewing, these questions demand immediate attention. See *Harvard Medical School Health Letter* 8, no. 5 (April 1983): 1-5; Hearings of the Subcommittee on Investigation and Oversight, Committee on Science and Technology, U.S. House of Representatives (Washington, D.C., May 12-13, 1981); and *Bureau of Radiological Health Bulletin* 15, no. 6 (Monday, May 4, 1981): 1-2.

13 John Dewey, *Individualism Old and New* (New York: G. P. Putnam's Sons, Capricorn Books, 1962; originally published, 1929).

Computer Pedagogy? Questions Concerning the New Educational Technology

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At this point in the "computer revolution" one can do little more than speculate concerning the long-term benefits or detriments that may accompany the extensive use of computers in education. Yet if we are to use this technology responsibly we must not hesitate to frame critical pedagogical and ethical questions concerning the use of this or, indeed, of any new technology in education. Few things are more important for our future than the education of the young, yet in our rush to embrace a new fad we risk overlooking the long-term deleterious effects of what may appear to be a harmless or progressive new technology. I wish to ask a few of what seem to me to be the most significant questions regarding computer-based instruction or education. Yet any such set of questions must be based, explicitly or implicitly, on one's view of the child and its maturation, emotional and volitional as well as intellectual. In attempting to pose a set of questions responsibly, I will make explicit the theoretical framework from which they arise. This article, therefore, falls into two parts. The first summarizes those elements of developmental psychology[1] that will later, in the second part, act as the matrix within which we may develop questions. The answers, the real answers, must await sensitive and careful research. But then should we not submit each of our educational initiatives to systematic theoretical and empirical scrutiny?

CHILD DEVELOPMENT

I begin with the explication of three aspects of Piaget's theory: accommodation and assimilation, cognitive structures, and development by stages. Once we have understood each of these concepts and their relevance to learning, the place (or misplacement) of computers in education gains clarity.

ACCOMMODATION AND ASSIMILATION

The polar processes of accommodation and assimilation form the logical center of Piaget's "genetic epistemology."[2] Although the newborn infant may completely lack all formal knowledge and, according to Piaget, all static "cognitive structures,"[3] the activities of accommodation and assimilation are sufficient to initiate cognitive development. Accommodation and assimilation can perhaps best be understood through their most vivid manifestations. In the case of accommodation, *imitation* serves this purpose, and in that of assimilation, *symbolic play* or *imagination.*

The process of accommodation is one in which the subject transforms or creates inner structures in order to accommodate a new object. This seems to be accomplished by a rehearsal, inner or outer, of the new experience. Piaget recognizes three levels of imitation: imitation through action, deferred imitation, and interiorized imitation. These provide the vehicle for the constitution of both operative aspects of thought and, through the last form of imitation, that of mental imagery. In the very young child the capacity for imitation, that is, pure accommodation, is present to an extraordinary degree. Not only is every aspect of the child's external environment an object of imitation, but also less tangible complexes of activities and emotions. The teacher's tender caress after a fall may turn up in endless variations, for example, as the comforting of a fallen doll or a wounded playmate. Thus are the moral, emotional, and aesthetic sensibilities of the child powerfully influenced by its capacity for imitation, for accommodation. Once one accepts the fact of accommodation, there arises the enormous responsibility for the educator to provide an environment fully worthy of imitation. Once again, I stress what should be entirely obvious, namely, that the objects accommodated should also be considered in their aesthetical and ethical dimensions. That is, the nursery should be beautiful, secure, and caring as well as instructional. In fact, as will become more evident later, the instructional component of early childhood education has essentially nothing to do with the teaching of conventional materials; rather, one should assist at this time in establishing the cognitive bases in the child for later and higher levels of learning. Thus the aesthetic and ethical dimensions become all the more important in the early years. In summary, child development hinges on the selfless capacity for imitation, that is, the ability to accommodate in order that something new can be absorbed from the environment.

Equally important is the complementary activity of assimilation, which Piaget defines as "the integration of external elements into evolving or completed structures of an organism."[4] When a child selects a nearby pine cone to become a loaf of bread, and a stone to be its knife, it is "assimilating" or integrating external elements (pine cone and stone) into an existing structure (domestic activity). Vigorous imaginative or symbolic play is an active projection of self. The whole world changes to serve the needs of the moment. Assimilation is an essential ingredient in development; it provides for continuity and, indeed, is necessary for recognition itself. Yet if it existed alone, no development could occur. The will and imagination to change one's world, whether in play or later through technological invention, must be coupled with the selfless capacity for accommodation. "Progressive equilibration" of these two processes is essential to intellectual growth, but it is not a static equilibrium. Rather it is a dynamic ebb and flow, a systole and diastole, a movement between receptivity and activity, between listening and speaking, which underlies cognitive growth.

COGNITIVE STRUCTURES

Out of the interplay of accommodation and assimilation arise what Piaget terms "cognitive structures."[5] Certainly the notion that all cognition, from ordinary perception to scientific discovery, depends on implicit mental structures is neither new nor unique to Piaget. The Romantic poets were filled with the idea that nature is an active agency that is constantly fashioning new organs of cognition in man, or cultivating those we have allowed to atrophy.[6] Goethe would write, "Every new object, well contemplated, opens up a new organ within us."[7] For our immediate purposes it does not matter at all whether we view the structures as innate but undeveloped (Chomsky and Fodor) or as constituted entirely by interaction with the environment (Piaget).[8] What is essential, however, is that we realize that education is concerned with the development of cognitive structures. Let us consider one such structure, its construction and its dependence on the feature of *action*—the structure of the "group of translations."[9]

Associated with the infant's gradually attained conviction that external objects possess an independent existence is his construction of a cognitive structure based on simple spacial coordinations. Geometrically these might be represented by such operations as: (a) $AB + BC = AC$; (b) $AB + BA = 0$; (c) $AB + 0 = AB$; (d) $AC + CD = AB + BD$. Through its own sensorimotor coordinations, and the experience accompanying them, the child maps out the laws of space. Perhaps this may first occur with the discovery of its own hand, or develop through a game of peek-a-boo. But gradually a cognitive structure is built up within the child out of its own actions that will allow it later to coordinate not only its own bodily movements but also its mental activities. Herein lies the critical point. Later cognitive activities rely on the development of suitable mental structures, and the construction of these structures is predicted primarily on action, not language. As Kurt Fischer writes in a recent article, "All cognition starts with action. . . . the higher-level cognitions of childhood and adulthood derive directly from these sensorimotor actions: Representations are literally built from sensorimotor action."[10] Piaget writes:

> From the 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 in one-to-one correspondence), knowledge is constantly linked with actions or operations, that is, with transformations.[11]

Piaget and subsequent workers have focused almost exclusively on those inner structures associated with human cognition. I would like to suggest that there exist two other aspects of the human psyche that demand similar attention both by developmental psychologists and by educators. I will term these the aesthetic and the ethical dimensions of the psyche. We may ask about them the very same questions we have asked about cognitive development, but for my purposes I will simply assert that development of a balanced life of feeling and purposive moral action requires a similar basis in early aspects of the child's development. Furthermore, I would maintain that accommodation and assimilation play an important role in this arena also. If we would have a child act kindly to another, lecturing or explaining about moral conduct is to demand a formal operative capacity of the child that it simply does not possess. Clearly, one's actions should set an example worthy of imitation. Similarly, the cultivation of a balanced life of feelings depends on an environment in which the use of color, form, materials, song, all unite to create a surround that fills the child with a lively experience of the beautiful. As for ethical conduct, so also for the beautiful. To lecture the five-year-old on aesthetics is a commonsensical absurdity. Yet by ignoring its active counterpart, one creates a void in childhood that cripples the child for later experience, action, and knowledge in just that dimension. One task of education, then, is to cultivate faculties that will later allow for perception and discernment in the ethical, aesthetic, and intellectual domains of human experience. We may turn to a rather unorthodox source for good counsel in this educational matter. Plotinus, writing of beauty and the faculty whereby it is apprehended, writes in the Ennead, "Beauty":

> For the eye must be adapted to what is to be seen, have some likeness to it, if it would give itself to contemplation. No eye that has not become like unto the sun will ever look upon the sun; nor will any that is not beautiful look upon the beautiful. Let each one therefore become godlike and beautiful who would contemplate the divine and beautiful.[12]

The "structures" or more metaphorically the "organs" that are required for cognition and for aesthetic and ethical judgment form themselves through action, imitation, and assimilation during early childhood. The Greek triad of the Good, the Beautiful, and the True still retains its significance as an educational ideal even in an age of relativism.

It is against this vision of child development that we must examine the place of computers in education. Certainly if one *defines* education in an impoverished way as the transmission of information and skills, then different and lesser questions will arise. But one can maintain, as I would, that up to at least the age of seven years we are seeking to nurture those capacities or structures on which subsequent development depends. In this context the place of the computer in early childhood education must come under very careful scrutiny.

STAGES

Few aspects of Piaget's theory have undergone greater critical discussion than his conviction that cognitive development proceeds by stages relatively unaffected by teaching efforts. That there is a natural rhythm to the development of the child is also a principle of Waldorf pedagogy, one that largely determines the content and form of presentation used in their classrooms. While the problem is highly complex, I would like to use some of the concepts of Piaget and Fischer without entering into the debate as to exactly when certain mental operations or functions reach maturity. Nevertheless, my questions regarding the use of computers in education depend on a developmental scheme. It is my conviction that the vast quantity of empirical evidence supports such a view, although detailed knowledge of the psychogenesis of specific structures or operational skills may be faulty.

As is well known, Piaget recognizes three major periods: (1) the period of sensorimotor intelligence; (2) the period of preparation and of organization of concrete operations; (3) the period of formal operations.[13] Likewise, Fischer speaks of three "tiers": (1) sensorimotor, (2) representation, and (3) abstract.[14] The first of Piaget's periods lasts from birth through the second year. Here there is a "prefiguration" in action and spacial coordination of mental operations that will appear later. For example, "on a small scale and on the practical level, we see here exactly the same operation of progressive decentration which we will then rediscover on the representative level in terms of mental operations and not simply actions."[15]

The second period, of concrete operations, extends from two to about twelve years, and contains two subperiods—one of preparation but with only preoperatory structure, and a second of concrete-operatory structures. Here mental operations develop but are restricted to those that bear on manipulable objects. Only with the onset of formal operations at age twelve do we see the capability to manipulate verbal propositions and abstract logical elements.

Piaget maintains that these stages are relatively immune to acceleration through training. Others will disagree. More to the point, however, is not whether one *can* accelerate normal development of formal operational skills but whether we *should* do so. Here it is a matter of informed judgment based not on the short-term goal of intellectual prowess but on long-term objectives that will include social and emotional dimensions as well. The recent raft of studies, books, and monographs on the dangers of early schooling should certainly restrain our optimism that artificially induced precocity yields long-term benefits.[16] If we can restrain our arrogance and allow ourselves to be guided by the child itself, then our task as educators should be to cultivate those facets of the child's nature that are critically active at that time. For example, in the first years when action, imitation, and imagination (or symbolic play) are vitally important, the child should not be set at a desk and drilled. Play should be allowed full space and encouragement. The objects of the nursery should be as simple as possible to enhance and even demand imaginative action (assimilation). A primitive doll made of a knotted handkerchief is infinitely superior to the usual explicitly membered and painted dolls replete with sounds, bed-wetting, and microprocessor control.

With these considerations we (at last) encounter certain of my fundamental concerns about computers in education. In our enthusiasm to do whatever is possible we neglect, as Weizenbaum writes, to ask whether we *should.*[17] By providing so completely for our children, do we not deprive them of their most creative faculties? By creating images for them, whether through television or a rouged doll's face, we still the imagination and blunt the senses. Waldorf nursery teachers constantly remark on the difference between "T.V. children" and those without television in the home. T.V. children do not know how to play, they cannot imagine what to do. If they are shown something to do, they perform it mechanically, without variation. It often takes months before the pine cone becomes a loaf of bread.

Let us ask this same question of the computer. Will it subvert or usurp, through its own extraordinary power, those capacities we should be seeking to cultivate in the young?

COMPUTERS IN EDUCATION

I should begin by making it completely clear that I am not a flat-earther. In my work as a physicist and teacher I use computers, large and small, constantly—whether to interactively run complex experiments in laser spectroscopy, to perform calculations, or to write this article. Perhaps because of this, the "mystique" of the computer has faded the more I have grown to respect its usefulness. The idiocy of those who maintain that one must start young to master the machine can be explained only by their complete unfamiliarity with computers. It is not a piano, which demands years of training and practice to operate. Especially as more and more effort goes into making programs or canned packages "user friendly," the computer becomes increasingly easy to use. This is not to imply that no intellectually exciting horizons exist in computer science, but that is an entirely different question.

Let me also say that I see little harm in encouraging adolescents (older than about twelve years) to use the computer. I would hasten to add that any curriculum should be balanced with vigorous programs in more traditional subjects including the arts, but this is obvious. My questions primarily concern the child at those stages of development before the "abstract" or formal operation period, that is, before the age of twelve.

We are used to hearing complaints about computers' replacing the teacher. As serious as this is, *my primary concern is that the computer may replace the growing child.* Consider the various components of any computer system: the central processing unit (CPU), the memory, and an input-output (I-O) device. Imagine the most powerful computer you care to: The CPU runs at blazing speed, the memory is practically infinite, and the I-O device is the most sophisticated touch-screen, color-graphics unit conceivable. Now add to this impressive hardware the software that certainly will one day be possible. It is a completely conversational and interactive language cueing not only on keystrokes, but perhaps on verbal or gestural commands. In one scenario this might be utopia for a computer-based pedagogy. To me it presents the problems in their most intense form.

The computer is like a fragmented projection of the human psyche. Each of its functions replaces one of our own. Just as we have replaced the child's active imagination (that is, the exercise of assimilation) through television imagery and certain toys, so the computer has the potential to replace nearly all the mental functions of the child. For example, memory has been found to be an essential factor in the successful operation of transitivity ($A = B$, $B = C$, so $A = C$).[18] We may possess the ability to perform this operation, but be prevented from doing so by an inability to retain all the elements in memory. The development of this operational ability depends, therefore, indirectly on the strengthening of memory. Reliance on an external device—the computer—can easily weaken that faculty. I would maintain that entirely similar arguments can be made with regard to the computational and logical functions of the CPU and program elements. These can replace and thereby undermine the development of corresponding faculties in the child. If the capacity to imagine has been undercut by television, interactive computer graphics threatens to complete the assault. Simply by pressing a button the child can transform his visual field at will. The use of language is here intentional, for there is clearly *no will* involved. The child is a passive doodler in such a situation, captivated by the images it can apparently create. But there is *no creation* here either. All these activities have been usurped by the machine. No one would contend that physical therapy is obsolete because the wheelchair has been invented. Neither should the computer be allowed to assume those functions that act as the foci for child development just because it can do so.

We may now profitably turn to another of the points discussed earlier—action. Piaget and others constantly stress that later mental operations are interiorizations of earlier sensorimotor activity. This has been a basic tenet of Waldorf pedagogy for over sixty years. Waldorf teachers, following Steiner's suggestions, commonly have their students run a triangle before proving that the sum of its interior angles is 180 degrees. Seymour Papert in his book *Mindstorms* recognizes this element fully.[19] In order to do "turtle geometry," one should *walk* the pattern. By observing what the body does we have the basis for both a concrete representation and later the formal or abstract description of that operation. The learning of represented and abstract operations must be based in action. But the computer distances us from action. It may assist in the development of formal operative functions, but it fundamentally interferes with learning at previous levels. We first execute geometry and mathematics through the coordinated activity of the body. The natural transition to the concrete or representational stage can be provided simply by pencil, paper, compass, and straight-edge. The equipment should be kept minimal, never intruding or exercising its own volition. The straight line should be drawn by the child, not the computer. Once again turtle geometry ultimately usurps important activities essential for the child's cognitive development. The turtle moves, not the child.

I have written about the computer as potential usurper of actions and assimilation, processes necessary for childhood development. I shall finish by considering that extraordinarily important function accommodation, which, as I described, is responsible for the formation of new cognitive structures. Moreover, I maintained that it is responsible also for the formation of aesthetic and moral structures. In truth these three are inseparable aspects of the process of accommodation. When the child imitates it cannot filter out the cognitive component of the lesson from its aesthetic and moral aspects. It imitates the whole, and the whole should be worthy of imitation. Yet the use of the computer is predicated on the assumption that cognitive structures can be cultivated in an aesthetically and ethically neutral environment. This is pure illusion. "No values" is just as much an ethical system as one that gives full conscious attention to them.

We must ask, in what sense can the child imitate a computer or its display? A pictorial answer is perhaps provided by the video-game imitations that fill current childhood behavior. The sounds and movements of Pac-Man become the movements of play. As much as I love technology, this image fills me with revulsion. On a less visceral level we may query after the cognitive structures we hope to induce via computer. If we learn, as Piaget maintains, through interaction of subject and object, indeed through actions in which "subject and objects are fused,"[20] if new structures depend on the profound imitative capacity of childhood, in what sense can computers teach? Shall small children mimic CRT displays? Are the structures thereby induced the ones we wish to fill our society?

Put simply, the world of childhood, environment and teacher, should be filled with the movements, patterns, emotions, images, and actions that, when transformed, should underlie adult intellectual, emotional, and moral life. By attempting to neglect the inevitable presence of the latter two, and by inserting what is properly a device involving formal operations into earlier periods of child development, we risk doing violence to the orderly and natural course of child development. Time and again, we have attempted to outdo, speed up, or improve on nature. Technological advance is predicated on our ability to do so. Yet we *must* ask what *should* be done, what in the light of our best understanding of child development is an appropriate use of a powerful technology, and what is inappropriate.

Notes

1 As will be evident, I draw heavily on the discoveries and views of Piaget, and also from the fundamental pedagogical principles underlying Waldorf education. See, for example, Jean Piaget, "Piaget's Theory," in *Handbook of Child Psychology*, 4th ed., ed. Paul H. Mussen (New York: John Wiley, 1983), vol. 1, pp. 103-28; and A. C. Harwood, *The Recovery of Man in Childhood: A Study in the Educational Work of Rudolf Steiner* (Spring Valley, N.Y.: Anthroposophic Press, 1958). For a description of child development that relates these two approaches, see Eva Frommer, *Voyage through Childhood into the Adult World* (Oxford: Pergamon, 1969).

2 Piaget, "Piaget's Theory," pp. 106-09.

3 Here Piaget differs with Fodor and Chomsky, who maintain the presence, in some form, of innate structures. The distinction is not important for my argument. Regarding this debate see M. Piatelli-Palmarini, ed., *Language and Learning: The Debate between Jean Piaget and Noam Chomsky* (Cambridge, Mass.: Harvard University Press, 1980). See also R. Gelman and Renee Baillargeon, "A Review of Some Piagetian Concepts," in *Handbook of Child Psychology*, ed. Mussen, vol. 3, p. 217.

4 Piaget, "Piaget's Theory," p. 106.

5 Ibid., pp. 120-25.

6 A. G. Zajonc, "Facts as Theory: Aspects of Goethe's Philosophy of Science," *Teachers College Record* 85, no. 2 (Winter 1983): 251-74; and idem, "Goethe's Theory of Color and Scientific Intuition," *American Journal of Physics* 44 (1976): 327-33.

7 J. W. Goethe, "Bedeutende Fördernis durch ein einziges geistreiches Wort," in *Goethes Werke*, vol. 13, ed. D. Kuhn and R. Wankmuller (Hamburg: Christian Wegner Verlag, 1955), p. 38.

8 See note 3.

9 Piaget, "Piaget's Theory," pp. 104-05.

10 K. Fischer, "Theory of Cognitive Development," *Psychological Review* 87 (1980): 481.

11 Piaget, "Piaget's Theory," p. 104.

12 *The Essential Plotinus*, trans. Elmer O'Brien (New York: New American Library, 1964), p. 43.

13 Jean Piaget, *The Child and Reality*, trans. Arnold Rosin (Middlesex, England: Penguin, 1976), chap. 3.

14 Fischer, "Theory of Cognitive Development," p. 481.

15 Piaget, *The Child and Reality*.

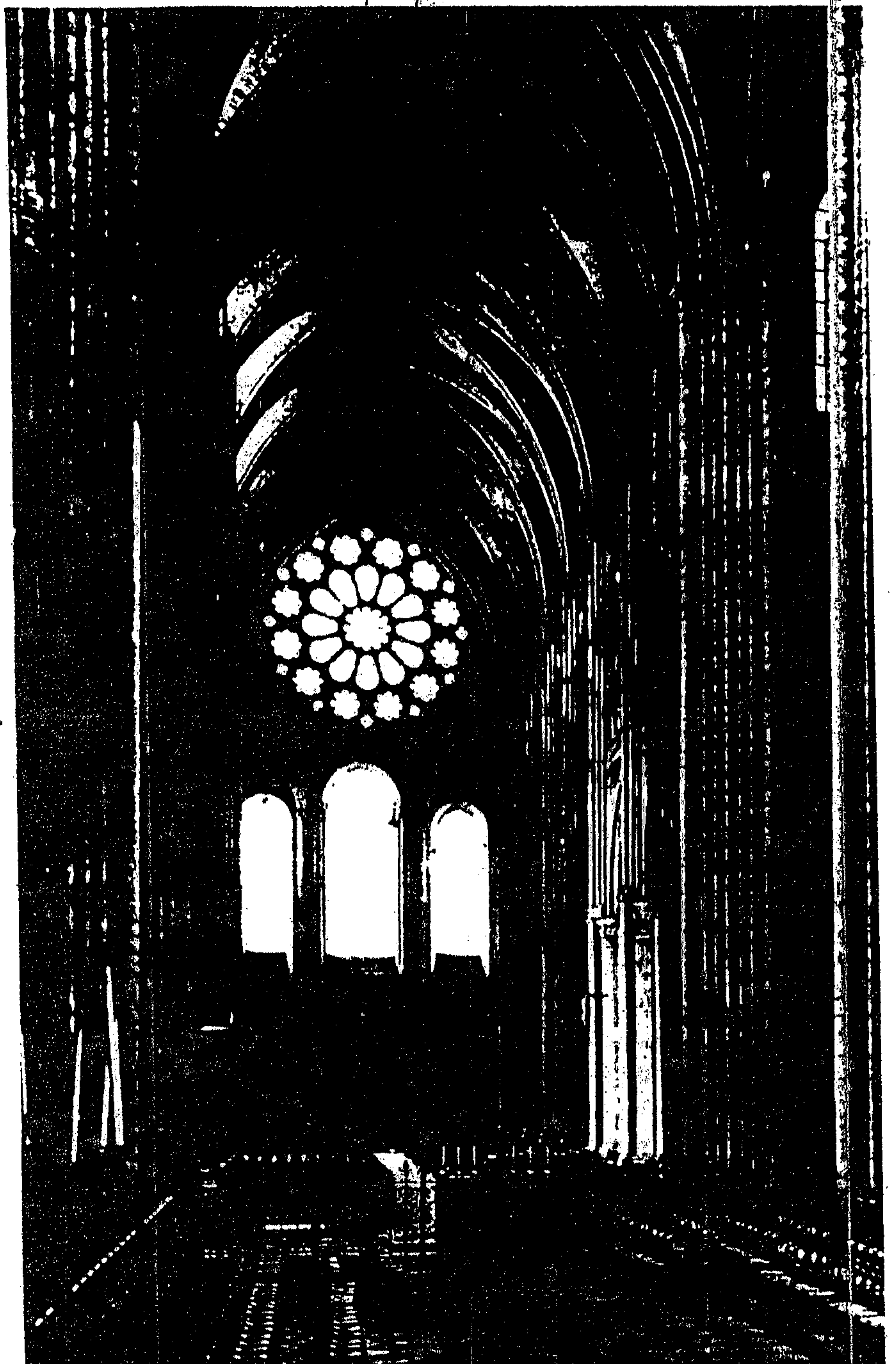
16 For example, Raymond S. Moore and Dorothy N. Moore, *Better Late than Early* (Pleasantville, N.Y.: Readers Digest Press, 1975); idem, *School Can Wait* (Provo, Utah: Brigham Young University Press, 1979); and Neil Postman, *The Disappearance of Childhood* (New York: Delacorte Press, 1982).

17 Joseph Weizenbaum, *Computer Power and Human Reason* (San Francisco: W. H. Freeman, 1976).

18 P. E. Bryant and T. Trabasso, "Transitive Inference and Memory in Young Children," *Nature* 232 (1971): 456-58.

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

20 Piaget, "Piaget's Theory," p. 104.



Chartres Cathedral

Light and Glass

ARTHUR G. ZAJONC

At the close of the twelfth century a miracle recurred in a town sixty miles southwest of Paris. Similar occurrences had been going on for hundreds, indeed, thousands of years there and elsewhere, but just then what had been prepared for centuries in Egypt, Greece, Mesopotamia and Europe flowered in a way that has not been equalled since. It was a miracle of light and earth.

Had you been there you would have seen artisans in preparation, gathering and drying beechwood logs from the forests, placing them together and setting them ablaze. The pure ashes so produced, free of stones and soil, were carefully collected. Nearby a furnace of stone and clay was being erected, fifteen feet long, ten feet wide and four feet high. Others were at the river gathering the fine sand, prepared and cleansed by the flowing river's waters. Two parts of the beechwood ash were mixed with one part of the sand and heated atop the upper hearth of the furnace for a day and a night. Then, at eveningtide, the fritted mixture of ash and sand was ladled into clay pots, and dry wood was added to the fire throughout the night. With the first light of day the metamorphosis was complete: sand and ash, transmuted by fire, had become glass. A substance of the earth had been transformed at the hearth of Hephaestus to become gemstones for a stained glass window in the cathedral at Chartres. Regardless of the color, the process was the same. Working with blowpipe and knife to shape in glass the mighty Christian-Platonic imaginations of God and universe, the medieval artisan re-enacted a practice that had originated in ancient Egypt—the manufacture of glass and the adornment of God's creation.

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The mystery of glass is inseparably linked to the mystery of light. Glass without light is dark, lifeless. Walk into the vast nave of Chartres at night illumined by the flickering light of the votive candles and the great walls of glass stand mute, asleep until the first light of day.

When completely clear, glass is invisible although substantial. Like light it possesses the paradoxical character of being something and yet in another way being nothing. Like the eye, being selfless, it remains unseen so that other things may be seen through it.

Likewise light, eternally unseen, selflessly illumines our world while its own nature seems forever to elude our grasp. In glass, water and air, light creates transparency. For Aristotle light was just this action, the "actualization of the potentially transparent." That is, under the aegis of light certain media—until then dark—could be lifted into transparency. It happens every time you turn on the room lights. Light was not a substance for Aristotle but a potent, actualizing force that, in a sense, completed the alchemical task of the fire. In the glass-maker's furnace earth was freed of its dross, of its opacity in order to become potentially transparent glass; but without light its crystalline qualities remain concealed awaiting, like a sleeping princess, the kiss of light.

What is the character of light? How has our understanding of its nature changed over time, and in what relationship to it do we stand?

In 1901 the physicist Max Planck reluctantly advanced the hypothesis that light was quantized, that is to say, that the structure or organization of light was in certain respects fragmented or atomized. Between the time of his proposal and the appearance of P.A.M. Dirac's famous text *The Principles of Quantum Mechanics* in 1930, the quantum theory of matter and of light underwent enormous development attaining, in all essentials, the form it has today. With it a new scientific imagination of light and substance was injected into the thought-life of the world.

During just these same years Rudolf Steiner was energetically advancing his "spiritual science" through lectures and books. He proposed a re-imagination of the world and man even more far-reaching than that being put forward by physicists at the turn of the century. Part of that re-imagination was an understanding of light as having arisen from the deeds of spiritual beings whose inner life

became over time the outer world we inhabit today. One cannot help but ask, what if any relationship exists between these two very distinct impulses that so powerfully entered the spiritual sphere of mankind at the dawn of the twentieth century?

Perhaps ironically, I feel that to answer that question we must begin with the Greek understanding of light, and particularly of vision. Against that background we can trace the evolution of man's understanding of light as a history of consciousness whose logical endpoint is the quantum theory of light.

Greek Vision

In antiquity the Greek conception of light displays the markings of human and spiritual experience. Consider for example the views of Empedocles and of Plato, who suggest that in order for sight to occur not one but *two* lights must be active, the external light of the sun and the internal light of the eye. Empedocles poetically describes the eye as like a lantern fitted round closely with membranes that protect the subtle luminous fire of the eye from the elements of nature. From the eye ray out beams as if from a lantern on a stormy night. Plato provides greater detail writing of the eye's emanation as mingling with daylight to form thereby a bridge or medium along which the sense of sight may operate. If the exterior light is absent the world is dark; if the interior is lacking then one is blind.

The notion of a radiant fire interior to the eye is alien to modern science, and yet it was so clearly self-evident to the ancient mind that the view persisted in various forms through the Middle Ages. I would suggest that to the ancient Greek the experience of vision was one in which the spiritual activity of seeing was given a standing equal to or greater than physical causation. They sensed a very real spiritual or "ethereal" emanation from the eye as part of the action of seeing. As time passed the vitality of that experience faded and the fossilized vestiges of the Greek view became part of a codified tradition to be found for example in the brilliant books of Euclid on the geometry of sight.

In that process of evolution the eye gradually became a passive *camera obscura*, or "dark chamber," on whose rear wall an image of the world was projected. No longer was seeing a human activity, but rather was understood as the inevitable consequence of the interaction of light and a physical organ.

In our century a new meaning can be given to the inner fire of the eye. The study of perception by psychologists has, in my view, yielded an appreciation for the Greek experience that can be framed in our own language. For over two hundred years physicians have been performing cataract operations on patients who have been blind since birth. Such operations offer us the opportunity to answer the question first put to John Locke by Molyneux: If an adult, blind from birth, were suddenly given perfect eyes what would he see? If sight is simply the natural response of a passive physical organ, then the hitherto unexperienced world of color, form, objects . . . everything, should flash into one's soul from the first moment the bandages are removed. This was, in fact, what patients and physicians expected. The sad and sometimes even tragic truth is, however, that the patient, now with perfect eyes, has the physical apparatus but still lacks the faculty of sight. Within the new visual organs a fire of intelligence needs to be kindled, and far more must be learned than we can imagine. The congenitally blind once given the physical ability for sight truly begins by seeing nothing and only very gradually, and often very painfully, learns to see extremely poorly. Most give up the project as too exhausting, going back to the less taxing and confusing world of blindness, literally reverting to a sightless world.

When I say that they see nothing I mean, of course, not that they lack raw sensations, but only that they can initially make nothing whatsoever out of them. I think of the sad case of an eight-year-old lad who after his operation was asked what he saw. His physician waved his hand before his unflinching eyes. Nothing. But then when asked to reach out he could, by touch, see the hand, crying out excitedly that yes he saw it now, and so learned to follow its slow movement across his field of view. But such progress was painfully slow and easily forgotten. The evidence of nearly seventy case studies shows that none ended with the subject seeing even as well as a child of three.

These facts should alert us to the wise activity that takes place in every one of our senses when we use them. Without a soul-spiritual activity of impressive scope we would be completely cut off from our surroundings. Seeing does indeed require functioning organs and an external light, but an inner soul-spiritual light is needed as well. I would suggest that when the Greeks, or Rudolf Steiner, speak of an emanation from the eyes, we should understand that the fire of

our will is joined with an extraordinary if inconspicuous intelligence that reaches out to the objects of perception. That intelligence is developed in early childhood when in our first three years we miraculously learn to walk, to speak, and also to organize the basis for our future life of thought.[1] The all-important aspect of thinking that forms raw sensations into meaningful impresions, of joining concept to percept, must not be overlooked or underestimated. Like walking or speaking, if seeing is not learned in childhood then it is essentially impossible to regain. The powerful forces that make this growth possible—forces that Steiner says are connected to the Christ—are no longer available to us in the natural way they were during our first three years.

The light of thinking is a metaphor possessed of real truth. During our early childhood a light is kindled within us, as Empedocles suggested. Without it we remain blind. We must bring our own light into the world to call its dark images to life. The glass images at Chartres remain silent without the light of day. Without the real light of our soul, so too would the infinite potential of nature never rise to expression. The world can only sing through us (as it did through Orpheus) as we play the instruments we have been given. Light is, as Aristotle says, an agency of actualization, of calling forth into being what rests latent around us. The ability for seeing was kindled in us by the first light of the world. St. Bernard was right when he saw in the penetration by light of the stained glass an image of Christ's conception and birth through the Virgin. His light conceives in us during childhood, all unawares, the light of the eye, that will be born as the gift of seeing.

Corporeal and Electrical Light

By the time of the Scientific Revolution of the sixteenth century, views regarding the nature of light had undergone enormous transformation, especially at the hands of brilliant Arab opticians. The views of Plato and Aristotle at which I have hinted, views still sensitive to spiritual and human dimensions of light, were discarded and in their place arose an essentially materialistic understanding of light. Two theories were established in the course of the seventeenth and eighteenth centuries. One proposed light as an effect arising from small physical bodies, while the second supposed light to be a movement or disturbance in a material medium. The former view found its most complete explication in Isaac Newton. It dominated eighteenth century scientific thought until Fresnel and others successfully resurrected the competing wave theory of light that had been initially advanced by Christian Huygens contemporaneously with Newton's corpuscular view.

The specifics of the theories need not concern us here. What is of significance for us is that both scientists conceived of light in terms of images drawn from the well-known material world around them. In the one case the image, appropriately provided by the Dutchman Huygens, whose life was surrounded by water, is one of wave motion. In the second instance Newton, the architect of gravitational theory and physical dynamics, advanced a theory of light as being variously-sized, immutable corpuscles. Both hypotheses draw their image entirely by analogy with physical sense experience. A trend begun already in the Arabic scientific community reaches here a logical conclusion: Light is a corporeal body alike in all essentials to every other physical body, even if light is enormously smaller.

These two physical hypotheses regarding the nature of light battled one another until the mid-nineteenth century when a startling suggestion was put forward by James Clerk Maxwell. Based on his analysis of the electrical researches of Michael Faraday, he suggested that light should be thought of not as a physical body but as an electrical disturbance. The equations of electromagnetism that now carry his name, the so-called Maxwell equations, can be recast into the form of a "wave equation" that describes, in this instance, the motion not of a water wave but of an electrical wave. This result, taken together with the concept of "field" first suggested by Faraday, ultimately revolutionized the nineteenth century's scientific image of light. Light was now to be understood as fundamentally connected to electricity.

The evolution of light from ethereal emanation to a corporeal body and then on to an electrical phenomenon is tremendously interesting. I see it as evidence for an evolution of consciousness, for a history of mind that reflects Rudolf Steiner's description of the evolution of man. In his "Letters to the Members" he summarizes the thought development of man in the following way:

> In the evolution of mankind, Consciousness comes down, step by step, along the ladder of Thought-development. There is a first stage of consciousness: here Man realizes Thoughts in his I, as Beings imbued with Spirit, Soul and Life. Then comes a second

> stage, where Man realizes Thoughts in his astral body. Here they appear rather as living and soul-endowed Images of the Spirit-Beings. At a third stage, the Thoughts are realized in Man's ether body; here they are only an inner life-stir, like the after-echo of a life of soul. At the fourth stage, the present one, Thoughts are realized by Man in his physical body, and represent dead Shadows of the Spirit.[2]

What we witness in the transition from the Greek imagination of light to that of Newton is, I believe, an instance of the development of consciousness from stage three to stage four. In the Greek experience of light something of the *life* of light still stirred; it was still a vital phenomenon to which man's own activity was linked in essential ways. By the seventeenth century such sensibilities had passed away to make room for the shadowy image of light as merely a physical body. Had we gone back earlier before the Greek to the Egyptian and Persian imaginations of light, we would have encountered "pre-scientific" images in which light was unthinkable as separate from a spiritual being of the Sun: Ra for the Egyptian and Ahura Mazdao for the Persian. In those civilizations one reaches back to earlier stages in the imaginal history of light. But our concern at present is with more recent developments and their import.

The history of light did not cease with Isaac Newton. Maxwell's electromagnetic theory of light took the development one step further, for no longer could light be understood as something analogous to the physical objects around us, but rather it was to be likened to what is in fact an invisible, or "sub-sensible" reality, namely electricity. To illuminate this further stage of development I would like to point to Rudolf Steiner's discussions of the four elements, ethers and "fallen" ethers.

Ethers, Elements, and Electromagnetism

The ancient Greeks saw the entire "sub-lunar" world as composed of four elements: Earth, Water, Air and Fire. Every object in so far as it was solid was possessed of the quality of Earth; in so far as it was fluid it had the quality of Water; in that it was areoform it was Air; and its warmth was due to the presence of the element of Fire. Within our planetary domain the elements appear to us now in mingled and impure forms, but nonetheless all things were conceived of by the Greek mind as made of only these four elements.

In numerous books and lectures Rudolf Steiner elaborates on the original perception of the Greeks with regard to the four elements by adding to the physical elements other "etheric" elements, termed "ethers," of a purely spiritual character. Already with the element of Fire one encounters a transitional case, for warmth is unlike the other elements in that it can permeate all three others but cannot have a physical existence apart from them. Steiner speaks about it as a bridge to the etheric world.

In the course of world evolution three other ethers arose: the light ether, the tone ether and the life ether.[3] Within the compass of this brief article I cannot provide an adequate picture of the ethers, but for our purposes it will be sufficient to connect them with the third developmental stage, the Greek stage, specified in the earlier quotation. In so far as thoughts are realized in man's own ether body they still display a vitality, a mobility in their formation that shows itself to be an "after-echo" of the supersensible origins of thought. The Greek understanding of vision with its vivid account of the interior fire of the eye reveals still a feeling for the supersensible character of light. They yet sensed, I believe, the place of light in the cosmos as an etheric reality whose ultimate origins were to be envisioned in myth. Rudolf Steiner also provides a beautiful account of the genesis

of light, one to which we will refer later.

The transition from the Greek imagination of light to that which arose following the Scientific Revolution represents a movement in consciousness from living to essentially lifeless thinking. The rise of materialism, whether in one's view of light or anything else, is a reflection of just this turning within man. Thoughts no longer light up within the etheric body of man as they once did, but now take hold of our physical nature.[4] The theories advanced by Newton or Huygens should be understood in this light. They are not advanced today because of new scientific discoveries nor by new data that calls for the overthrow of antiquated ideas. Rather one should understand the evolution and growth of science as an expression of deeper inner transformations in the soul-spiritual nature of man and mankind. The corpuscular and wave theories of light were *physical* theories, and as such accurately reflected the changed soul-spiritual nature of man in the seventeenth and eighteenth centuries.

In view of this, how can one understand the rise of the electromagnetic theory of light in the nineteenth century? Of what is it a reflection? And what about the current state of science with its quantum theory and relativity?

Here one can turn to a further elaboration of the concept of the ethers. Rudolf Steiner describes three "fallen" ethers as counterparts to the three higher ethers (light, tone and life ethers). Each of the ethers has in part fallen prey to the work of adversarial beings whom Steiner calls by their mythic names: Lucifer, Ahriman and the Asuras. Under their influence a new fallen etheric domain is created. The fallen light-ether Steiner identifies with electricity, the fallen tone-ether he connects with magnetism, and the fallen life-ether with a so-called "third force."[5]

Against this background I would suggest that one sees in the electromagnetic theory of light a further evolutionary stage in which man has descended even further from physical-material theories to "sub-physical" theories. Thoughts do not naturally light up within our etheric bodies as they did for the ancient Greek. I would suggest that at least within the scientific community, neither do thoughts grasp the physical body as they did in Newton's time. Now they descend still further to a fallen etheric domain in which we too participate. Nor did the development stop with the electromagnetic theory of Faraday and Maxwell, but continues on to this day showing itself particularly vividly in the modern quantum theory of light. In this, light takes on an extraordinary non-physical character that seems constantly to defy the concepts of classical physics, that is to say the physics of Newton and the thinking that is imaged in the physical body (stage four).

It is important to remark at this point that the recent developments in the scientific understanding of light from Faraday on, are double-edged in nature. On the one hand as they are traditionally presented these theories continue the descent of thought still further into domains ruled by adversarial beings. Yet they also, even in their fallen guise, reveal their higher origins. Faraday's concept of "field" is rich with implications, and the contemporary dialogue around the "new physics" and the paradoxes of quantum mechanics provide magnificent challenges to the inflexible, lifeless modes of thinking born with the Scientific Revolution. Yet for all that they lack an essential element if one would move from natural science to spiritual science, namely what is sometimes called by Goethe the "moral dimensions" of our natural world.

Light as Deed

Just at the time Max Planck was first advancing his proposal of a quantum theory of light—that is, just as thoughts on light were descending to the level of the third fallen ether—Rudolf Steiner, then forty years of age, began to lecture regarding his spiritual understanding of man and universe. Implicit in that action was an attempt to "redeem thinking," as he would later call it. That is, to so re-enliven thinking that what was once a reality for the Greek mind would become so again for us, but now through a kind of self-conscious, alchemical transformation of the human soul. No longer would such thinking be "natural," a gift from the gods, but would rather be the fruit of human self-development.

Steiner recognized the scientific work of Goethe to be an important step along this path.[6] In it was initiated a science of natural phenomena that appreciated the full range of human experience in nature. By attending with utmost care to the phenomena themselves, the investigator not only learned to sense, and in fact *see* nature's lawfulness, but following Goethe's scientific method an important added nuance remained that would be expunged through the method of orthodox science. For Goethe urged the investigator to develop a kind of

objective life of feelings, for example in one's relation to color. Through steeping oneself in a particular color experience and listening for the soul-echo it calls forth, an inner or psychological dimension to color can become part of the investigator's realm.[7] Just such aspects are, of course, excluded from the facts of normal science, and yet they provide the subtle nourishment required for the development of spiritual organs of cognition.

Engagement with the natural world in accordance with Goethe's scientific method, therefore, offers the possibility for a reanimation of thinking. To an enlivened thinking the delicate, soul character of the phenomenal world can gradually become more and more articulate. It is no accident that an artist of the highest order first suggested this mode of scientific inquiry, for in it science and art are bound together. Under the influence of the striving that here occurs, new stirrings arise in man's ether body and, in the world imagination provided by Steiner, our strivings are answered by the harmonious responses of spiritual beings, foremost among them the powerful archangel Michael. Steiner characterizes his response in the following words:

> Michael's mission is to convey to men's ether-bodies those forces by which the Thought-Shadows may again acquire *life*. To these new-enlivened Shadows, Souls and Spirits from the supersensible worlds above will incline themselves. And with these, Man, unbound and free, will be able to dwell, even as he dwelt with them of old...[8]

Gradually, as new faculties of cognition unfold and a new, enlivened thinking dawns, ancient imaginations will take on new voices and present themselves in contemporary dress. An example of this is Rudolf Steiner's account of the genesis of light according to his spiritual scientific researches.

In a remote past, prior even to the creation of the Earth as we now know it, angelic beings passed through a stage of their development that can be likened to our own today. They too then possessed an inner life of thought and moral action, for good and for ill. Their inner life was as rich and challenging as ours is now. At the end of that era all that they had thought and inwardly enacted, passed out or died into the embrace of the higher hierarchies. In our present era the thoughts of those angelic beings reappear as the light and darkness of our world. The inner life of the past dies and becomes the future outer vesture of nature.[8]

The implications of his account for our own inner life are clear and intimidating. The inner world we now cultivate, our thoughts, feelings and actions are not of concern to us alone. In a distant future they too will "die and become," they too will form the light and darkness of a future world. We become thereby a community of creator-beings who slowly rise to self-conscious participation in world formation.

I think back to the miracle of glass-making enacted in the workshops that surrounded the rising walls of the great cathedral at Chartres. The transformation of sand and ash by the action of fire to become the potentially luminous gemstones that would form the walls of the Heavenly City, seems an apt metaphor for the alchemy of soul manifested in our struggles to make of ourselves a pellucid vehicle for the Logos-Light of Christ. If the miracle of the Virgin Birth is recapitulated every dawn through the windows at Chartres, then in us also a birth occurs with every effort we make to take a gemstone from the hearth of our soul, and holding it beside the like work of our neighbor, we together wait for the first light of dawn.

NOTES

1. Rudolf Steiner, *The Spiritual Guidance of Man and Mankind,* (Spring Valley, NY: Anthroposophic Press, 1950), Chapter 1.
2. Rudolf Steiner, *The Michael Mystery,* trans. by E. Bowen-Wedgwood and George Adams (London: Anthroposophical Publishing Co., 1956), p.21.
3. Rudolf Steiner, *Occult Science,* (London: Rudolf Steiner Press, 1969), pp. 161 ff.
4. Rudolf Steiner, *The Michael Mystery*, pp. 19–20.
5. Rudolf Steiner, *The Etherization of the Blood,* see especially the questions following the lecture.
6. Arthur G. Zajonc, "Facts as Theory: Aspects of Goethe's Philosophy of Science," in *Goethe's Science Reappraised* edited by Frederick Amrine, *et al.* (Amsterdam: Reidel, 1987) and in *The Journal for Anthroposophy*, Numbers 40/41 and 42. Rudolf Steiner, *Goethe the Scientist* and *Theory of Knowledge Implicit in Goethe's World Conception* (New York: Anthroposophical Press).
7. Goethe, *Theory of Color,* in his collected *Scientific Writings*, edited and translated by Douglas Miller (Boston: Suhrkamp, 1988). Also see Rudolf Steiner's lecture of April 3, 1912, in *The Spiritual Beings in the Heavenly Bodies and in the Kingdoms of Nature.*
8. Rudolf Steiner, *The Michael Mystery*, p. 20.
9. Rudolf Steiner, "The Connection of the Natural with the Moral-Physical," Dec. 10, 1920.