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The study undertakes to clarify and redefine some of the concepts underlying the relations between visual perception and thinking. A sample bibliography suggests sources for future research. Psychological and psysiological theory is shown historically to have separated the two mental functions in principle. Correspondingly, present-day education, mostly devoted to verbal and numerical skills, has not yet integrated art instruction sufficiently in its program. To bridge the gap, visual perception is shown to involve cognitive mechanisms while theoretical thinking relies on imagery. Abstraction operates as the connection between the two functions. Images are abstract representations, which serve as theoretical models in the sciences. Visual material for science education must be prepared at an appropriate level of abstraction and must conform to the perceptual rules by which the relevant features of the subject matter can be translated into visually comprehensible form. This calls for more explicit use of the psychology of perception and the experience of the artist than is now common in the practice of visual education. Art instruction will come to be considered the prime training ground of visual cognition, one perceptual imagery is recognized as the vehicle of productive thinking in all disciplines. (Author)

Final Report

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STUDY OF VISUAL FACTORS IN CONCEPT FORMATION

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HEALTH, EDUCATION, AND WELFARE

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CONTENTS

Summary

The report deals with research on visual thinking, that is, the interrelations between visual perceiving and thinking. The study was undertaken to clarify some of the underlying psychological, educational, and philosophical concepts and to redefine them in the light of recent findings. A sample bibliography is offered.

Present-day education, mostly devoted to verbal and numerical skills, has not yet integrated art instruction sufficiently in its program. Correspondingly, in psychological and philosophical theory, perception has been treated as different in principle from thinking. Recent evidence can be interpreted to show that visual perception involves cognitive mechanisms and that theoretical thinking relies on imagery. Abstraction operates as the bridge between the two functions.

Images are abstract representations, which serve in the sciences as theoretical models. Visual material for science education must be prepared at an appropriate level of abstraction and must conform to the perceptual rules by which the relevant features of the subject matter can be translated into visually comprehensible form. This calls for more explicit use of the psychology of perception and the experience of the artist than is now common in the practice of visual education.

Art education cannot expect to receive its place as a respected equal among the academic disciplines as long as it remains narrowly conceived and taught as an "aesthetic" matter. Once perceptual imagery is recognized as the vehicle of productive thinking in all disciplines, art instruction will be considered the prime training ground of visual thinking, visual cognition, and visual experience.

Introduction

The research summarized here deals with a problem of psychological theory, namely, the relation between perception and thinking. Although theoretical in nature, the study was provoked by an educational challenge, namely, the traditional split between verbal and numerical skills on the one hand and the exercise of sensory activities on the other. Historically, the medieval division between the liberal and the mechanical arts distinguished between mental and manual skills, establishing the former as superior, the latter as inferior. The trivium of the verbal arts and the quadrivium of the numerical arts defined an intellectual aristocracy, which demoted painting and sculpture, as manual skills, to the ranks of the mechanical handicrafts. This led to a similar hierarchy in education, which even in our own time is focused on words and numbers and tends to consider the arts supplementary. The present research is based on the conviction that this situation needs to be remedied, but that it can be remedied only by a broader conception of art education. Art education, instead of limiting itself to specifically aesthetic criteria, would seem to be in need of developing into a much broader discipline of visual training. Such visual training -- an important aspect of perceptual training in all sensory modes -- can be considered a basic condition of productive learning in any field of study whatsoever. If so, it belongs in the very center of education.

On this assumption, it seemed imperative to suggest a review of the corresponding situation in psychological theory. The traditional distinction between perception as the source of information and conception as cognitive processing is no longer tenable either on theoretical grounds or in practical application. Percept, concept, abstraction are notions in need of basic reconsideration.

Methods

What is called for in such a situation is not only experimental and practical research on particular aspects but first of all an overall strategy, a survey of the total field to be investigated. The areas to be brought together under the heading of visual thinking are cultivated by essentially separate and independent disciplines, such as the psychology of perception, concept formation, problem solving, and learning. Philosophy has long been concerned with these problems, and the history of science offers a rich case material. The role of language needs to be examined as well as the attitude of art educators toward cognitive problems.

The range of the task at hand seemed forbiddingly large, but the attempt has to be made at this point. In order to arrive at an integrated approach, it was not sufficient to select and collect relevant material in the various areas. It was necessary to go further and to use the material for the purpose of testing the basic approach of the present study and then to formulate guide lines for future research and educational practice on this empirically fortified basis.

Given the number of the different areas of science, philosophy, and art to be examined, it was, of course, impossible to cover all of the relevant material in each area. A sampling of the literature, based on informed guesses, was the best that could be done.

The final problem was that of how to submit the yield of the study through the present report. Since the value of the completed research could not consist primarily in what had been carried out but, at best, in the clarification of what will have to be done in the future, a detailed presentation of the material reviewed would have beclouded the principal purpose. The only feasible procedure seemed to be that of putting the chicken on ice while serving up the broth, i.e., of summarizing the conclusions instead of spelling out the data on which they were based. This has been attempted in the following succinct report, which omits all explicit references. It is a theoretical statement with four main objectives:

(a) a preliminary reformulation of basic concepts;

(b) a manifesto of educational principles in need of application;

(c) a lay-out of a general plan for subjects to be included in future, more particular research;

(d) a sample bibliography.

The report is the outcome of a piece of "developmental" research, designed to perform a seeding function.

Results and Findings

I. Thought mechanisms in perception

(The bibliography will be found in the back)

Perception and reasoning can be treated as separate functions of the mind only as long as perception is assumed to consist in the mechanical recording of stimulus material. Because of this traditional assumption, psychologists have become accustomed to excluding perception from the area of cognition. The view reflected in this usage is no longer tenable. The elementary phenomena of perception, well established experimentally, can and should be interpreted to show that many of the mechanisms known from the psychology of thinking operate even in perception. Direct perception, therefore, needs to be considered as the primary realm of conceptual thinking.

I A. Direct perception.

1. Distance. One of the fundamental accomplishments of thought is that of extending the range of information and understanding beyond the station point of the observer. Vision as a distance sense not only extends the human environment beyond the reach of the body but also enlarges the "life-space" to include the astronomical universe. "Broadness of view," a trait of good thinking, is found in the distance sense of vision not only as a metaphorical analogy but literally as its most direct application. By learning to relate distant events to what happens close-by in direct experience, the mind exercises and trains a basic cognitive function.

2. Selectivity. All cognitive activity presupposes selection. The mind must focus on the subject to be considered and thereby lift it out of the continuum of the total given world. To establish the proper range of a problem -- how much to include, how much to exclude -- is a crucial aspect of problem solving. Perception is selective by its very nature. The senses have developed in evolution not as recording devices but as instruments signalling the presence of opportunities and dangers: food, enemies, mates. The studies on the so-called inborn releaser mechanisms in nimal behavior have shown that instinctual responses are geared to well defined signals of simple shape, color, motion.

A basic kind of perceptual selection focuses attention on change, rather than on constant factors of the environment. The latter, biologically less relevant, tend to vanish from consciousness.

Ocular fixation is a primary mechanism of perceptual selectivity. Actively it picks pertinent items from the environment; passively it trains the center of optimal vision on striking features of the visual field (strong lights or sounds responded to by infants, etc.) Ocular accomodation facilitates a similar economy of attention in the third dimension. It singles out the

pertinent range of depth by throwing it into focus, leaving closer or more distant areas blurred.

3. Shape perception is the first level of concept formation. It does not consist in the mechanical scanning and recording of elements but in the grasping of relevant structural features. Genuine perception as distinguished from the mere impingement of stimuli, takes place when the sensory input can be fitted to available categories of shape, e.g., the simple geometry of circle, square, sphere, cylinder, cube. Visual concepts subordinate particular instances to generalities of form and thereby make them comprehensible. From the point of view of this approach, the distinction between percept and concept is not tenable.

A useful comparison can be made with the studies on pattern recognition by machine. There again the task consists in discovering structural patterns (of letters, numbers, etc.) in a variety of given shapes. However, machines do not accomplish the task by field processes but by the mechanical fitting of templates or variation of dimensions.

Since the image of visual objects, in order to be perceived, must be formed on the twodimensional receptor surface of the retina, various projective distortions result, from which the "objective" size and shape must be recovered by means of perceptual abstraction. The correct perception of size requires an evaluation of the projective size in terms of the total spatial framework; i.e., the "true" size of the object is deduced from its location in the spatial framework. This involves two basic cognitive mechanisms: (1) to see and evaluate an item in terms of its relation to the surrounding context; (2) to extract the properties of the item from those of the context.

The perception of shape requires abstraction of a considerably higher level because the objective threedimensional shape to be drawn from the retinal projections is not contained in any one of them. The image of the cube is derived from its innumerable projections, none of which actually contains it. This goes beyond the traditional conception of abstraction as the drawing forth of common elements from a population of particular instances.

The constancies of brightness and color also are due to perceptual abstraction. The perceived brightness of an object derives from the physical reflectance (albedo) as evaluated in relation to the brightness distribution in the total surrounding field. Similarly, the perceived hue of an object is based on the physical stimulus as evaluated through the object's place in the overall organization of color in the environment.

4. Perception of relations. Instead of recording elements item by item, visual perception constantly involves the apprehension of relations between elements or, as in the case of the "constancies" mentioned above, of relations between the whole of the visual field

and some item within it. The establishment of relations is one of the principal cognitive mechanisms. In perception it operates, for example, in the so-called rules of grouping by similarity (shape, color, movement, etc.), as described by gestalt psychologists. Here again the mechanism shows a high degree of sophistication. Perceptual grouping is not simply the connection of items that are identical or resemble each other by some mechanical criterion. Rather, resemblance is relative: whether two items resemble each other, or differ from each other, in size or color depends on the distribution of these perceptual dimensions in the total field. Also, two items quite similar in piecemeal terms by occupying different locations in the overall structure cannot be grouped in perception without neglect of that overall structure.

The perceived structure of an image, e.g. of a painting, changes when juxtaposed with that of another image. A painting will look differently, depending on the nature of another painting with which it is paired. The two basic mechanisms operative here are assimilation and contrast; i.e., the two perceptual structures will change either in the direction of assimilating to each other of of accentuating the contrast between each other. This amounts to a tendency of viewing the juxtaposed items together as a whole and of modifying them in the interest of an overall structure.

The relations between visual items tend to be viewed, learned, and remembered as generic rather than particular. This is evident in the findings on transposition. If an animal learns to prefer the larger of two items, this learning tends to transfer to the size relation of any two items, regardless (within certain limits) of their absolute sizes.

The experiments on stimulus equivalence show that perception as well as behavioral response are based on generic structural properties. Within limits, a response learned for a particular pattern will apply to patterns of similar structure. Percepts, in other words, are visual concepts. The cognitive mechanism of what is called subsumption in logic operates also in the task of finding analogies, as used in intelligence testing.

I. B. Relation to memory traces

Among the modifications perceptual material undergoes in memory there are those which clarify or sharpen the form of visual concepts. Two antagonistic tendencies are at work simultaneously. One of them works toward simplifying the trace, i.e., toward increasing its generality or raising its level of abstractness; the other sharpens characteristic features of the original percept. Both tendencies serve to fashion perceptual concepts into more efficient cognitive tools.

The influence of memory traces upon direct perception creates a complex structural interaction. The visual trace material is fitted to directly perceived images, modifying and

completing them. For instance, what is known from previous visua experience about the inside of an object becomes a genuine part o the direct percept itself. The hood of a car is seen as containi the motor, not just known to contain it. Similarly, if a part of a directly perceived object or situation is absent, the memory image of the complete object or situation is a genuine component of what is perceived: one sees the missing part as missing. This means that perception, instead of being limited to what stimulate the retina at a given moment, results from the totality of the observer's pertinent visual life-time experience. In terms of thinking, it is an example of interaction between what is known and what is newly learned.

Visual identification can be defined as the fitting of nor images, formed in the memory trace system, to the particular give instance. For example, whether or not a shape encountered in a picture on in physical reality is recognized as a human figure wi depend on how the percept fits the structure of the perceiver's norm image of the human figure.

II. Perceptual imagery in thought mechanisms

Psychology has rarely faced the problem of what precisely is the vehicle of thought. What mental medium gives existence to thought? Around the turn of our century, experiments based on introspection were carried out to determine what goes on in the mind when a person thinks. The overall result was puzzlingly paradoxical. Subjects reported that thought processes occurred in their consciousness while they were working mentally on the solution of some problem, but they denied that they were aware of any images.

These results have to be evaluated in the light of the traditional belief that mental images must have the individual concreteness of realistic pictures. It is a belief exemplified early in Western philosophy by the notion of eidola (school of Leucippus and Democritus), and it is most clearly formulated in the writings of Locke and Berkeley. These philosophers maintain that generic ideas could not be represented by particular images because any such image would have to possess the properties of on individual case. There could be no generic images.

However, experiments showed that generic images are not only possible but rather typical. When subjects were asked to report what they experienced when they were given words such as flag, train, or snow, they typically said that they experienced images of overall shape or movement, e.g., a waving flag of unspecified design. Titchener's examples of his own introspecti contain similar observations.

Since such images can assume any level of generality, it possible that during the solving of theoretical problems they become so abstract as not to seem images at all. Observers whos

training and background makes them think of images as fairly detailed, realistic pictures, similar to those experienced by eidetic persons may fail to acknowledge them when they are reduced to little more than purely topological spatial relations of the Venn-circle type.

It is pertinent to ask here what exactly are the mental equivalents of the diagrammatic scribbles used by lecturers on the blackboard and commonly found as illustrations of theoretical presentations. Drawings cannot be treated simply as replicas of mental images, but they are likely to share some of their properties. In preliminary experiments, students were asked to make abstract drawings of such concepts as freedom. The subjects experienced little difficulty in translating their personal views of such ideas into meaningful visual shapes of a more or less geometrical nature. Of particular interest is the opportunity to show the gradual emergence of a person's concept through the stages of development in one drawing or a series of drawings on the same subject matter. Such studies can make it clear that we are dealing here not merely with "illustrations" of finished conceptions, worked out in some more "abstract" fashion prior to the drawing. Rather the development of the drawing itself serves as a way of clarifying the conception in the first place. These preliminary experiments should be followed up by more systematic work with different age and social groups.

III. The Nature of Abstraction

III A. Theoretical Considerations

The theoretical discussion of the problem must center around the notion of abstraction because abstraction is the bridge between perception and thinking. Traditionally, perception and thinking were considered as excluding each other. Percepts were supposed to be limited to particular instances (Berkeley, Locke) whereas conceptual thinking was confined to generalities. Correspondingly, thinking was assumed to begin where perception ends.

This assumption made it very difficult to understand how any connection between the sensory and the conceptual realms could ever come about. Since the individual things and events that constitute our world have an infinite number of traits in common, the mere mechanical extraction of common traits would serve no useful purpose. It would create an infinity of concepts, most of them useless. In order to abstract from the items of experience, one must have an idea of the traits one looks for; in other words, one must possess a general notion of what one is looking for before one begins to extract it from experience. This vicious circle has played a decisive role in discussions of induction as a scientific method. Induction, it has been pointed out, is not the way by which a scientist arrives at his concepts. He must have a concept before he can look for evidence to support it.

In order to get out of this impasse, it is necessary to realize (a) that perception does not consist in the recording of

particulars but in the grasping of generalities (cf. Section I) and (b) that the mental images available to thought are of a generic nature (cf. Section II). The findings in these two areas supplement each other and establish the continuum leading from primary "percepts" to theoretical "concepts". This continuum makes abstraction possible.

Progress has been blocked by the artificial distinction between abstract and concrete. These two terms have been employed as though they were mutually exclusive, i.e., as though they could be used for classification of the facts of experience. In popular language, concrete things are "tangible", directly perceivable, whereas abstract ones ("ideas") are not accessible to perception. A particular table or chair is supposed to be concrete, whereas generalities, such as "table" or "friendship" or "equality" are called abstract. This usuage, widespread also in philosophical and psychological theorizing, reflects an artificial distinction between percept and concept. It is necessary to realize that all facts of experience are particulars in themselves but can also serve as generalities when they are related to less generic structures. For example, a circle drawn on paper is a particular thing in itself but serves as a generality when it represents the roundness of faces, balls, apples, celestial spheres. The circle, therefore, is concrete and abstract at the same time. The same is true for "ideas," such as friendship, a particular phenomenon, which can serve as a generality for a kind of human relation.

How does abstraction come about? What are its mechanisms? Here again we are hampered by views, derived mostly from traditional logic, which promote a misleading distinction between conceptual thinking on the one hand and perception on the other, between science on the one hand and the arts on the other. The insistence on induction as the main instrument of scientific exploration corresponds to the belief that an abstraction is necessarily distilled from a number -- a large number -- of cases. This approach is not helpful. Although scientists may seek confirmation of their hypotheses by the statistical treatment of a sufficient number of cases, a concept can be drawn, and often is drawn, from a single specimen, just as an artist can produce a more or less abstract portrait of one individual person. It is true that a concept, once formed, is subject to constant revision and modification as new instances are scrutinized. These instances, however, do not influence the nature of the concept by virtue of their number but by the structural changes any one of them may suggest. In the arts, a painter's conception of "man" is not modified by the sheer number of humans he examines but by whatever striking corrections, amplifications, or deeper insight any one individual instance may induce him to apply.

According to traditional logic, an abstraction can be brought about by the selection of any one trait, or number of traits, from specimens possessing them. Such arbitrary and mechanical extraction, however, would be useless. Actually, abstraction by the selection of traits, proceeds according to two criteria, in the arts as well as in the sciences: (a) traits are selected to represent the

essentials of the phenomenon's structure, not just any accidental property; (b) traits are selected according to their relevance to the investigator's or observer's purpose.

It is necessary, however, to go further and to assert that, more often than not, abstraction does not consist in the extraction of traits at all, but rather in the formation of structural patterns found in, or imposed upon, the phenomena represented by the concept. Compare here what was said earlier about the perception of shape (Section I). Just as the perceived cube is not the sum of traits inherent in its projections, scientific or artistic conceptions do not come about typically by the subtraction of traits from a group of manifolds but are patterns structually akin to the patterns of the phenomena to which they refer. One can express this by saying that scientific and artistic concepts are types rather than extr[illegible]s of elements. Types are model structures. Actual empirical cases or instances can be described as more or less close approximations of these model structures.

III B. The Cognitive Status of Images

Images can serve three principal cognitive functions, which will be labeled here with the terms: signs, pictures, and symbols. (These terms as well as similar related ones are used in a great variety of meanings by various writers. Their choice is necessarily arbitrary.)

(1) An image serves as a sign to the extent to which it stands for a particular content without reflecting its characteristics visually. Letters and numerals are the most prominent examples of images used as signs. They are chosen by mere convention, not to convey a resemblance with the shape, color, or structure of the items they stand for but to be easily and clearly perceived, remembered, and discriminated from each other. Some traffic signs and many trade marks function at least partially as signs. The so-called innate releasing mechanisms described by ethologists in biology are signs: simple colors, or shapes, or motions, to which animals respond instinctually. In man, the response to signs is based on learning.

(2) An image serves as a picture to the extent to which it portrays objects or activities by grasping and rendering some relevant qualities of their shape, color, movement etc. Whereas signs are not abstractions, pictures always are. (I am excluding here images that, for all practical purposes, are duplicates of the object they represent; such mechanically faithful copies are of little relevance to the problems discussed here.) As works of art, illustrations, or diagrams, pictures serve to present relevant features of the situations they depict in order to clarify and interpret these situations. Pictures come at all levels of abstraction: from highly realistic images (e.g. certain kinds of photograph) to non-mimetic (so called "abstract") ones as found, e.g., in diagrams or in modern painting or sculpture.

(3) An image serves as a symbol to the extent to which it portrays things located at a higher level of abstractness than it is itself. Symbols serve mainly as perceivable illustrations of ideas. They translate structural properties of ideas into correspondingly structured perceivable patterns. Like pictures, symbols come at any level of abstractness.

As a rule, images that function as pictures are also symbols, and vice versa. This means that the images considered under (2) and (3) are located on the scale of abstractness somewhere between the two extremes of the most generic ideas (maximum abstraction) and the most particular instances (minimum abstraction). They function as pictures with regard to what lies below them on the scale of abstraction, and as symbols with regard to what lies above them. A scientific diagram showing, let us, say, a parallelogram of vectors is a picture of any practical situation in which such a combination of forces may occur, but it is also a symbolic representation of what happens quite in general when two forces combine. Similarly, Michelangelo's painting of the creation of man is a picture of the episode described in the Book of Genesis and a symbol of the animating effect of creative energy. In short, such images are a bridge between man's direct perceptual experience and the most rarefied ideas of which the human mind is capable.

III C. Abstraction and Alienation

Abstraction is described here as the connecting link between perception and thinking. To abstract does not mean to withdraw from direct experience but rather to find a generic pattern within given, more particular instances. It was pointed out earlier that this view is in opposition to the traditional one, which describes abstraction as a withdrawal from experience. In fact, the term abstrahere can be taken to mean to draw from but also to withdraw from. There are indeed many instances in which the distance between the abstracted pattern and the facts of experience from which it is derived serves as a protection against reality; it may also mean estrangement from reality. In the arts, the highly abstract style of primitive art has been described as an escape from the frightening complexity of the natural environment. The geometric formalism frequently observed in the art work of schizophrenics can be attributed to a detachment from modifying stimulation. In the psychology of normal persons also, detachment can make for formalism, pedantry, thoughtlessness, callousness.

In teaching, simplified models, although of great value in other respects, may remove the student from the complexity and the excitement of the "real thing." The educational threat of alienation is ever present in the use of verbal language and numerals. These sets of conventional labels stand for abstractions but are not abstractions in themselves. As visual and aural shapes, words and numerals are not pictures or symbols but signs, which display little perceivable kinship to the referents for which they stand.

Hence the danger of "verbalism" or the routine manipulation of mathematical data according to rules whose meaning the student ignores.

An unfortunate consequence of the traditional approach to abstraction has been the tendency to put a premium on the capacity to ignore the reality context. In psychology, the outstanding example are certain experiments with brain-injured patients. When the patients failed to carry out meaningless or paradoxical tasks (drink from an empty glass; write: "snow is black"), they were pronounced incapable of abstraction. Such misleading interpretations make it necessary to emphasize that neither in the sciences nor in the arts does the distance between abstract statement and its referent require or even permit a neglect of the primary reality context.

The need of maintaining contact poses a particularly serious problem in the many instances in which cognition deals with reality situations not by manipulating them directly but through models that resemble them only with regard to particular structural properties. In the arts, "abstract" (non-mimetic) painting or sculpture makes statements about reality by patterns that do not "resemble" it. In arithmetic and algebra, it is necessary to deal with pure quantities. However, alienation from what the cognitive processes are about cannot be avoided by simply returning to the primary reality situation: the "abstract" artist cannot take refuge in the realistic style of the past, just as recourse to "practical applications" in arithmetic can be more confusing than helpful.

Anthropological studies of number concepts have shown that at early levels of mental development the notion of quantity is not readily separated from the particular life contexts to which quantities apply. (It may be unthinkable to add up the number of children belonging to two different tribes or to answer the question: "How many animals have I left if I subtract three horses from seven chickens?"). In our own culture, the same difficulty is found in students brought up in "unsophisticated" settings. This difficulty is hardly met by trying to impress upon the student the purely negative notion that mathematics specializes in operations that absurdly contradict "real life." (Compare, as a recent example, the insistence on the fact that sets can be made up of the most unrelated items!) What is needed, instead, are perceptual models that illustrate the cognitive operations at the appropriate level of abstractness. In geometry, of course, this has always been common practice. In arithmetic, the various methods of teaching by means of colored rods have begun to meet this need admirably.

IV. Visual Thinking in Science and Art

The basic assumption of the present research plan is that all genuine thinking (as distinguished from the kind of mechanical operation that can be carried out, for example, by a computer) takes place in the medium of perceptual imagery. Perceptual imagery is not limited, of course, to the sense of sight; but the present

investigation, in order to make its range manageable, deals only with vision. If the underlying assumption is correct, we need to know (a) what kind of image offers a suitable medium for theoretical thinking as practiced in the sciences or philosophy, and (b) what mechanisms of thinking are involved in the kind of image produced in the arts. Here again, only a few condensed suggestions can be offered at this point.

Theoretical thinking relies heavily on verbal language. However, verbal language is not a medium of thought. As a set of verbal, aural, and kinesthetic shapes, it lacks the necessary high structural order, found, for example, in music, as well as the ability to portray the objects of experience (an ability of which visual imagery is the outstanding example). Language assists theoretical thinking by helping to stabilize and standardize the concepts derived by the mind from perceptual experience. Language provides a set of normed signs, suitable for labeling the facts of experience and enabling human beings to communicate about these facts in a convenient manner.

The objects and operations of theoretical thinking themselves, however, cannot be verbal. The fact that they take place predominantly in the visual realm is amply documented in the history of science. Visual models of the universe or of the nature of matter are found at early stages of civilization and persist in the highly refined sciences of our century. For instance, the model of the sphere or of concentric visual shells is found in the cosmology of antiquity as well as in the atomic model of Rutherford and Bohr. Nor is such imagery limited to the natural sciences. The type of image used to describe the nature of physical objects or processes serves to give shape to philosophical, social, or psychological concepts. For instance, the relation between centric shape and spatial infinity, explored in the visual models of modern astrophysicists, have their prototype in the conception of God as a sphere of infinite radius -- an image proposed in the fifteenth century by the philosopher Nicolas Cusanus. Visual models are constantly produced on the blackboards of lecture halls as well as in treatises and textbooks, not as mere "illustrations" of concepts dwelling in a non-perceptial medium -- for what medium could that be? -- but as the pictorial reflection of the images serving as the vehicle of thought. In the social sciences and in economics, visual models of structural patterns are commonplace, and the theoretical constructs of Freud are no less visual than those of Einstein.

An essential aspect of scientific training is that of learning to "see" the relevant features of a microscopic preparation, a chemical experiment, or a machine. Such productive vision requires the interplay of perception and mental imagery (cf. Section I B), i.e. the contact between the directly perceived pattern and a pertinent abstract model. Needed for this purpose is, on the one hand, a target that displays the pertinent structure with sufficient clarity and, on the other, an observer possessing an adequate model in his memory.

Appropriate visual aids are essential for the acquisition of such models. The enormous increase in visual materials and equipment tends to obscure the fact that the mere display of images does not necessarily fulfill this task. In fact, a great deal of what goes under the heading of visual aids is still an outgrowth of the attitude which the research plan here presented tries to discourage. It is the basic assumption that the senses provide only the raw material of experience, to be elaborated secondarily by some "higher" processing power of the mind. The assumption seems to be that the mere confrontation with some kind of authentic image will give students the needed subject matter. However, if it is true that an essential part of grasping, interpreting, and understanding goes on within the perceptual experience itself, the image, in order to fulfill its function, must meet at least two conditions: (a) it must be at a level of abstraction geared to the student's level of comprehension and to the facts he is to glean from the material (e.g., a geographical map for elementary school children should take into account the level of visual complexity the children can handle and should show no more than the few simple facts they are expected to grasp and to remember); (b) the image must use the perceptual qualities of shape, color, brightness, movement, in such a way that they explain to the eye the relevant features (e.g., one must inquire whether the color sequence of light green, dark green, and pure blue, which stands for the triad 3, 6, 9, in the Cuisenaire sticks is really perceived as a perceptual gradient; or whether a particular photograph of a pump or a printing press truly translates the salient properties of these mechanisms into visible characteristics). One can formulate this requirement by saying that a good instructional image does not simply present a given object "by itself" but rather the "functional value" of the object's relevant properties.

The perceptual rules by which instructional material fulfills its function can be obtained from psychology, and the practical application of these principles is the domain of the artist. It is revealing to examine manuals of visual education as to how much space they devote to these fundamental requirements.

The gap between art instruction and the other areas of study shows up both ways. On the one hand, visual material for the schools is prepared without explicit reliance on what artists know about the organization of meaningful form. On the other hand, the usual approach to art instruction takes little cognizance of the fact that the comprehension and interpretation of perceptual shapes is the basis of cognition in all fields of study and knowledge. There is too little unity among the principles by which the student draws biological specimens, geographical maps, or historical charts on the one hand and makes pictures for the art teacher on the other. Art instruction cannot legitimately claim the important place in the curriculum due to it unless it conceives of art as training in the vital skill of visual thinking. The role of the senses must be considered for education as a whole, and the principles by which they fulfill their function must transcend the walls separating fields of study from each other.

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The references given here must be limited in two respects. They cannot pretend to present exhaustively the literature on any one of the many subjects referred to in the report. Instead, a few suggestive samples are given which may escape the researcher looking for literature through the ordinary channels, plus some of the more basic sources suited to serve as springboards for further research. On the other hand, and this is the second limitation of this list, some of the obvious basic stand-bys have been omitted in order to keep the bibliography from becoming unnecessarily bulky.

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Conclusions and Recommendations.

The foregoing report presents reformulations, theses, demands. The experimental and historical research presently available has generally been done in limited and isolated areas. Coordination of these findings under a unifying purpose can hardly be undertaken before the artificial conceptual dichotomies are eliminated from the underlying theory. Once this theoretical reorientation is accomplished, it will be possible to do the more explicit research envisaged in this report, for example, studies of thought mechanisms in perception, visual models in scientific theory, nonverbal thinking, and cognitive problem solving in artistic practice.

While the present survey is limited to the sense of sight, similar investigations will need to concern the cognitive mechanisms operative in other sense modalities, especially the auditory and the kinesthetic, and the integrative functioning of the various senses in this respect. Motoric exploration, invention, and construction also must be considered as an inseparable aspect of perceptual cognition.

The author of this report expects to enlarge on some of the issues raised here in future publications of his own.

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ERIC Report Resumé

The study undertakes to clarify and redefine some of the concepts underlying the relations between visual perception and thinking. It offers a sample bibliography suggesting sources for future research.

Psychological and psysiological theory is shown historically to have separated the two mental functions in principle. Correspondingly, present-day education, mostly devoted to verbal and numerical skills, has not yet integrated art instruction sufficiently in its program. In order to bridge the gap, visual perception is shown to involve cognitive mechanisms while theoretical thinking relies on imagery. Abstraction operates as the connection between the two functions.

Images are abstract representations, which serve as theoretical models in the sciences. Visual material for science education must be prepared at an appropriate level of abstraction and must conform to the perceptual rules by which the relevant features of the subject matter can be translated into visually comprehensible form. This calls for more explicit use of the psychology of perception and the experience of the artist than is now common in the practice of visual education.

Art instruction, on the other hand, will come to be considered the prime training ground of visual cognition, once perceptual imagery is recognized as the vehicle of productive thinking in all disciplines.