A RATIONALE FOR OPEN-ENDED SCIENCE EXPLORATION

Science educators generally agree that hands-on experience with materials is necessary for learning science concepts, but there is real and significant difference over what forms these experiences should take. This is revealed in the variety of approaches given in textbooks and other curriculum materials. It was most evident in the large scale programs developed in the late sixties. The Science Curriculum Improvement Study (SCIS), Science-A Process Approach (SAPA); The Elementary Science (ESS), advocated similar curriculum goals, but were different in the design of the classroom activities. With the exception of ESS and a few other derivative programs, most curriculums have students use materials in an instrumental manner. By this I mean that concepts are chosen first and then examples are found to illustrate them. The emphasis was on the scientific validity and accuracy of content. Whether these experiences were personally meaningful to the students or teachers seem to be given minimal consideration. Those programs that did pay attention to the latter such as ESS did so in an ambivalent manner.

A fundamental assumption underlies these approaches. It is assumed that students interact with these materials in an objective, detached manner giving their total attention to those salient characteristics illustrating the concept in the textbook. During my work with students over the years I have observed that a certain segment of the student population if not the majority interact with materials in a very personal manner. In their initial explorations and encounters there is more likely to be a strong affective reaction. The materials are more likely to become props in an impromtu, short-lived drama than instruments for doing a scientific experiment. It is my contention that this kind of behavior is a natural mode of assimilating experiences with material and it is a way of exploring that should be encouraged rather than considered as immature. Support for this can be found in some biographical sketches of creative scientists and in the working patterns of artists. It has been given special attention by John Dewey and the developmental psychologist, Heinz Werner. Both place it at the beginning of any process which involves creative use of materials. The following sections give specific examples of students exploring materials, and places this mode of exploration in a general developmental framework.

Examples of Students in an Exploratory Mode

Over the past fifteen years I have worked at The Children's Museum in Boston designing interactive exhibits, and teaching in Boston classrooms as well as in a large number of after-school programs. In all these situations I chose to present what I call intrinsically interesting materials to students. These are ones which have high aesthetic appeal and evoke a strong affective response. I also attempted to present them in a manner whereby some of the time was open ended exploration followed by a more structured specific exploration. Thus the students blew bubbles with drinking straws on a table creating all kinds of interesting patterns. Then they would carry out an investigation to determine if the angles at which bubbles joined together formed a recurring pattern. When there is a social context that allows exploration with materials in a playful manner, and adults who support such behavior, I have observed a special kind of interaction appear.

This initial exploration does not proceed in a systematic, logical manner. It is often repetitive, more attentive to the aesthetics of the materials rather than the geometric, technical characteristics, and more resembling how an artist would play with the materials than a scientist. The magnifying glass is more likely to become a prop for a Sherlock Holmes scenario than an investigative tool for finding out about insects.

Here are some specific observations I have collected working with students in classrooms and observing them exploring with interactive exhibits:

A fifth grade girl arranges her batteries and bulbs into a street scene where the light bulbs are taped to one end of a popsicle stick fixed to a piece of cardboard. Having done so she creates a very brief story describing what is happening in this scene...

Students place corks having small pieces of mirror on top of rigid wire that can be made to oscillate. Light shining on these pieces of mirror produces small spots of light which dance around on the wall. As an eleven year old girl observes three spots of light jumping around on the wall she comments that it looks like a preacher marrying a man and a woman. A little later when she observes six spots of light jumping about on the wall, she describes the action as a family fighting with each other.

A boy, eleven years old, spends 15 minutes in the Bubbles exhibit at The Children's Museum moving a piece of tubing between two pieces of plexiglass forming a thin sandwich holding some soap solution. The tubing has air coming out of it and allows the user to make bubbles cells or make small ones grow large. As the boy moves the tubing around allowing the air to form large cells he narrates a story about an adventure in outer space.

A group of 4th grade boys spend an entire hour bending and taping plastic molding to one wall of a classroom attempting to engineer a ramp that will allow a marble to roll over it and near the end jump over a short gap which has a can of water below it. These boys refer to the exploits of Evil Knievel--a daredevil motorcyclist who is known for his exploits of riding cars or motorcycles over rivers or deep canyons. As the marble rolls over the ramp and makes the jump over the gap, they shout enthusiastically, even identifying with the marble by moving their bodies, mimicking the ups and downs of the marble as it rolls along.

These and many other scenes I have observed at The Children's Museum and especially in afterschool programs have led me to make several conclusions regarding how students explore with materials. These are not new observations. Others have made similar comments in other areas, but I wish to place them within the context of science education.

First, there is a great deal of sensuality to children's exploration. It is more tactile and kinaesthetic than visual. Anything involving the kinaesthetic has great appeal to them. The thrill of bike riding, roller skating or ice skating is not left at the classroom door. The ball rolling down a ramp, the top spinning on its axis, food color moving in water, is identified with in a very concrete fashion. The students are also moving with these materials, if not actually moving their bodies, feeling the sensation in an emphatic manner. When there is this kind of sensual attraction to materials there can be continued explorations for many hours. I have seen students make ramps and runways or blow bubbles for many sessions challenged by the variety of possible configurations they can create. They do this more with an attitude of seeing what they can with the materials rather than what they can learn from them. However, they learn a great deal about the properties of the materials as they explore in this manner.

Secondly, reactions to certain kinds of materials, especially those introduced in science classes, are not received in a neutral mood. Seen for the first time, these materials elicit an aesthetic as well as a cognitive challenge. The actions of the attraction and repulsion can be related to all kinds of interpersonal situations. As noted by psychotherapists, characteristics of materials can suggest all kinds of affective states and how a person reacts to them can be a strong indicator of their emotional state. Erick Erickson in a long and extended study of block play reports on how various arrangements of blocks symbolize the ongoing working out of emotional problems of children.

Thirdly, this kind of exploration is a way of becoming acquainted with the physical properties of the materials. It is a way of becoming bonded to them. Once this kind of interaction with materials happens, they stand out among the plethora of things we encounter everyday. This kind of exploration is significantly different than the usual laboratory exercises suggested in the teachers' manual. Usually, the student manipulates materials to find answers to questions posed by the teacher. In this other kind of exploration the student creates his or her own questions and finds ways to answer them.

There is a great discrepancy between the way children explore materials and become acquainted with phenomena as compared to the way they are directed and allowed to do so in the school environment. If one of the goals of science education is to have students develop scientific intuition and an understanding of basic concepts that is long term, then it is very important to determine how best students assimilate experiences with materials.

If the kind of behavior just described is acknowledged at all by educators, it is often looked upon as developmentally early, and therefore inappropriate. It is also seen as uncharacteristic of scientific methodology. In most science textbooks, science is presented as a method that proceeds in an orderly fashion. The "scientific method" is the orderly process of making observations, generating hypotheses and the designing and carrying out of experiments to confirm or disprove these hypotheses. Very little is said about the role the scientists' personal reactions to the phenomena he or she is investigating or to what extent affective reactions color their observations and influence the generation of hypotheses and theories.

Scientists and Artists Identifying with Materials and Phenomena

Recent biographies of some scientists by a few historians have revealed that there exists a deep personal involvement in what they are investigating. As an example there is the recent biography of Barbara McClintock--one of the few women scientists to win a Nobel Prize. Evelyn Fox Keller,(1983) the author, relates not only details of McClintock's line of research, but also singless out McClintock's more personal reflections about her work. At one point in the book there is a series of quotes where McClintock describes her close identification with the maize plant, the subject of her research. Speaking about her frequent examination of the maize cell structure under the microscope she says:

> I found that the more I worked with them the bigger and bigger they got, and when I was really working with them I wasn't outside, I was down there. I was right down there with them, and everything got big. I was even able to see the internal parts of the chromosomes - actually everything was there. It surprised me because I actually felt as if I were right down there and these were my friends.

In the same context she also relates:

> As you look at these things, they become a part of you and you forget yourself. The main thing is to forget yourself.

Keller(1986) discusses in the biography and in a separate book on women scientists to what extent McClintock's fundamental approach arises out of the fact that she is a woman working in a male-dominated institution, or whether her basic epistemological position is out of the current scientific mainstream. Keller proposes it is the latter and shows how McClintock's fundamental theoretical position, her method of research and basic epistemology differ from the mainstream. To what extent this proposition is valid remains to be further substantiated. If there is some substance to it, and it can be shown that other creative scientist share a similar orientation, then there are real implications for the design of science curriculum. For it has been a stated goal of those who design curriculum that students emulate the methods of real scientists. Even if this mode of doing research is not found in the majority of scientists, it can be shown that other creative ones practice a similar kind of personal involvement.

Charles Darwin's theory of evolution is considered a major intellectual achievement providing a broad framework for understanding much of the natural world. His theory is based on extensive observations while travelling around the world. Howard Gruber(1978) has done extensive research on the life of Darwin. He examined closely the notebooks of Darwin as well as other historical resources. He arrived at the conclusion based on these resources that Darwin was a very passionate observer of nature proposing that it bordered on the erotic in the symbolic sense of the term. Gruber may be overreaching about the latent symbolism, but it is evident that Darwin was deeply and personally involved with his observations.

Given the traditions and ethos of modern science one can only speculate on the relationship of scientists' personal inclinations and their scientific work. The prevailing ethos of the scientific community is to downplay if not ignore these personal connections. The growing field of the history of science and technology may help make these connections more evident. Robert Root Bernstein(1985) in his investigations of scientists' personal lives has shown an interesting correlation between their avocations as artists and their creativity as scientists. He proposes that the aesthetic skills gained from their avocations gave them special insight enabling them to make new discoveries or create new theories. Much more research in this area needs to be done to make more explicit the role that aesthetic affect plays in the work of scientists.

Artistic Exploration of Materials

For the general population of adults and perhaps most scientists, becoming personally identified with materials doesn't happen often. There is one profession where it is central to its mission. Artists such as painters, sculptors, and crafts people are more sensitive to the properties of materials. Their psyches become closely intertwined with the materials they are using. Consider this passage from the writings of Kandinsky:

On my palette sit high, round rain-drops, puckishly flirting with each other, swaying and trembing. Unexpectedly, they unite and suddenly become thin, sly threads which disappear in amongst the colors, and rogouishly skip about and creep up the sleeves of my coat....it is not only the stars which show me faces. The stud of a cigarette lying in the ash tray, a patient staring white button lying amidst the litter of the street, a willing pliable bit of bark - all these have physiognomies for me...As a thirthteen or fourteen year old boy I bought a box of oil-colors iwth poennies slowly and painfully saved. To this very day I can still see these colors coming out of the tubes. One press of my fingers and jubliantially, festivelly, or grave and dreamy, or turned thoughtfully within themselves, the colors came forth. Or wild with sportiveness, with a deep sigh of liberation, with the deep tone of sorrow, with splended strength and fortitude, with yielding softness and resignation, with stubborn self-mastery, with a delicate uncertainity of mood- out they came , these curious, lovley things that are called colors.

Kandinsky is not an unusual example of this kind of sensitivity to materials. On reading biographic commentaries by the artists themselves about the way they work with materias a common theme emerges. It is often expressed more in terms of the dialectic relationship they have with their materials. One example of what is meant by this is a comment made by Henry Moore.

Every material has its own individual qualities. It is only when the sculptor works direct, when there is an active relationship with his material that the material can take part in the shaping of an idea.

Other artists who shared this basic approach were the painters Itten and Albers who had a major role in shaping the basic curriculum of the Bauhaus--an institution which had a major role in influencing modern art. Another sculptor noted for his great respect for materials was Brancusi. Coming from a background of Romanian craftsmen his deep respect for the materials of marble and wood are well-illustrated in such pieces as the Kiss and Promethus..

This approach is not of recent origin. It had been mentioned by Western artists for centuries. Michelangelo is said to have seen the statue David in a piece of marble suggested by its special shape. The characteristics of the material suggested this particular form. He released it from the marble. Even among non-Western artists there is a similar attitude toward materials. Edmund Carpenter(1966) describes this very nicely in describing the work of an Eskimo carver. Taking the piece of ivory in his hand the carver starts chipping away. After a while a seal emerges. The carver says that he released it from the ivory.

If we are to accept these statements and observations about the way the artist or craftsperson works with materials as more than rhetoric or the romanticization of the artistic process, then it suggests that at least among some adults there is still an involvement with materials similar to that of children. Some artists and philosphers of art such as John Dewey go so far as to claim that it is essential to the artistic process. Hofmantel (1952) sums up this process in a manner reminiscent of the Eskimo carver.

As long as objects are to you merely an antithesis to your "I," you will never grasp their real essence, and no amount of intensive observation, description or copying will help you to do so. You may succeed, however, if you are able to divest yourself of your "I" by projecting it into the object so that the object can begin to speak in your stead...

Is it possible that the creative scientists as part of their coming to know the phenomena they are investigating also identify with it in this subjective manner. McClintock sounds as if she is operating in this mode when she completely forgets herself when observing maize cells. It can be argued that the child and creative scientist's dialogue with materials functions more than a way for expressing their affective attitudes in a symbolic manner. It is a way of becoming acquainted with these materials and therefore serves a cognitive function.

Physionomic Perception and Syncretic Thinking

Researchers in the disciplines of psychology and related areas have not given much attention to this mode of thinking. Clinical psychologists such as Erick Erickson have often commented on the therapeutic role art activities can have in patients working out their emotional problems. However, very few have gone as far as to propose that this mode of exploration may be part of the cognitive development of children as well as serve as an important step in the learning process of adults. One psychologist who did was Heinz Werner. He spent most of his professional life researching and writing about the expressive nature of human explorations of materials. Drawing upon the anthropological literature of non-Western societies, clinical studies of the severely disturbed, and his own research with children and adults, he formulated a theory of human development in which the affective reaction to the material world assumes central importance.

In The Comparative Psychology of Mental Development he develops this theory introducing the concept of physionomic perception. The mode of exploration that has already been described of students playing with science materials, artists creating expressive forms or sculptors or painters or scientists such as McClintock carrying out her research are examples of this concept. He chose the word physionomic to relate it to the inate tendency to project emotional states when viewing the human face. The subtle variations of the mouth, eyes, muscular tone, are read as indicators of joy, sorrow, anger or other emotional states. In the previous examples of spots of light dancing on a wall reflected off pieces of mirror on vibrating rods, students have explicitly commented that the motion makes them anxious. In contrast, both adults and children have expressed the soothing feeling of watching food color move slowly through a jar of water forming spirals and vortices.

Werner(1978) proposes that even though this level of perception may be primitive and is most noticeable in children, it continues to function in an important way for some adults.

Though physionomic experience is a primordial manner of perceiving, it grows, in certain individuals such as artists, to a level not below but on a par with that of "geometrical-technical" perception and logical discourse.

It is this second kind of perception that is considered the essence of scientific thinking, and is that which is given great if not total emphasis in most science curricula. Werner does not examine the thinking process of scientists, but it is implied that physionomic perception is prior to the objective categorization of properties of materials. It is a way of becoming acquainted with the material world and assimilating the experience so that it has personal meaning.

In addition, it is part of a broader process of taking in the totality of an interaction with materials as differentiated from focusing closely on specific characteristics. Werner, Piaget, and Ehrensweig(i967) among others have proposed that there is a type of thinking that happens at a global level. Calling it syncretic thinking, they describe it as a process where the total scene, the total field of characteristics of a material are taken in all at once. There is a lack of differentiation among parts of the object. The overall, broad features of the object are the basis of identification.

This is illustrated by our identification of faces. Gombrick and Hochberg(1970) speculate on the very complex process by which we identify faces. They point out that despite the continually varying specific features of a face, we manage to recognize the same person. For instance, Gombrick juxtaposes pictures of Bertrand Russell when he was four years old and when he was in his nineties. Even though there is this great gap in age there is something about the overall facial features which we can recognize. Hochberg suggests that this kind of recognition arises out of a perceptual process that distinguishes between higher order and local features. The work of the cartoonist or the caricaturist are examples of how the artist can abstract these higher order features and represent them with a few strokes of the pen. McClintock stated that she had come to know the maize plant so well that she could walk through a field of these plants and be able to predict what their cell structures would look like based on certain specific features and the overall structure of the plant.

The mental process being described here is different than the formation of gestalt images. Writers such as Ehrensweiz propose that syncretic thinking is much broader in scope. It is more a matter of how we attend to experience than how we represent it. He proposes that there are two kinds of attention--one which is global in nature, taking in the entire scene or object, the other which is specific, focusing on specific characteristics. The two make up an interacting process by which images are created. Both are essential for understanding the world, and essential for creating new concepts. Ehrensweig sums this process up by stating:

The growth of new images in art and of new concepts in science is nourished by the conflict between two opposing structural principles. The analysis of abstract gestalt elements is pitted against the syncretic grasp of total object...

He describes this process as one which functions at an unconsious level. We can't consciously control it. It is interesting that McClintock at one point in Keller's biography describes her thinking as acting like a computer where she seems to be processing and integrating data far more complex than she can possibly be conscious of.

Implications for Science Curricula

Most science textbooks and curriculum as well as exhibits in science centers are organized in a manner that I call the smorgasboard approach. Each chapter in the book is a collection of activities that are supposed to illustrate a wide variety of concepts. The materials are usually very different from each other in the experiments, and the manipulation to achieve the required results varied. The text introduces many new facts, definitions and concepts. What is supposed to give coherence to all of this is a broad concept such as energy or electricity. This overall concept is so abstract and broad that it has no meaning to student or teacher. In science centers students do have the option of playing with one exhibit for an extended period of time. However, most school visits to science centers are too brief and infrequent to allow students to fully explore a specific phenomenon.

If the propositions mentioned about the essential role that syncretic perception has in the creating of new concepts in science has validity, then it implies that students need to do much more open-ended exploration of materials than what is now the general practice. They also need to do it in a manner that allows them to become personally identified with the phenomena they are investigating. This means that there should be a reconfiguration of the curriculum where phenomena are investigated in an extended, in-depth manner. Only then will students begin to develop a global image within which they can assimilate the more specific concepts that will help them understand what is happening. By taking such an approach they will take on a greater challenge and have a much richer experience.

These recommendations are made in the context of designing a more effective science pedaogy. A more general reason can be given for making these changes. It would result in a more humanistic education. John Dewey(1934 in the context of speaking about the role of art in human experience had this to say:

> The moment when the creature is both most alive and most composed and concentrated are those of fullest intercourse with the environment, in which sensuous material and relations are most completely merged.

This could as well be said for the general goal of good science teaching. Students are most involved when challenged affectively as well as intellectually.