SCIENCE AND CHILDREN: RECONSTRUCTING EXPERIENCE

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Science does wonders for us. It fills our world with ideas to drive our imaginations; things we never dreamed of to inhabit our dreams. It is a ceaseless source of novelty, of wonderful speculation about almost everything that matters to us. It creates for us continually new ways of seeing, feeling and thinking, because it is everywhere in flux. It is, at its core, an enormous work in progress. With its sister technologies, science fills our towns and homes with marvels that we take for granted: eyeglasses, televisions, refrigerators, cars, and personal computers. We have become accustomed to expect such invention to continue. It is a given of contemporary life.

But like any large human endeavor, science has a dark side. For many people it is a source of intimidation, fear and threat of dreams that turn to nightmares. It is a relentless source of pedantry and slavishness to technique. It demands conformity in thought to dogma cloaked as fact. It is an enormous, stagnant file of formulas, facts and laws. It claims a final authority to which ordinary people must defer. With its sister technologies, science fills our world with weapons of horrible destruction, poisons to all forms of life, and great brown clouds. We have become accustomed to expect such invention to continue. It is a given of contemporary life.

What about science is important to communicate to children? What about science is empowering and liberating and humanizing? How can science be experienced so that not only are its crucial aspects understood, but it also supports and enriches the natural interests and activities of children? New ways of thinking about these questions arise from taking the risk of interpreting science from the perspective of a child's life in society. This requires unraveling some entanglements in children's experience of science in schools, museums and the media. It also requires a broadly developmental view of children's scientific capabilities. The problem is to discover an interface where fundamental aspects of science coincide with fundamental aspects of children's physical, intellectual and social growth.

Unless we honestly acknowledge that science is both intimidating and liberating, deadening and enlivening, frightening and wonderful, it is difficult to see the dilemma in children's experience of it. To many in the scientific community, the humanly damaging aspects of science are the result of a misunderstanding or misuse of science. Science is supposed to be humanly neutral. But it is not. Children don't much care about what some idea of science is supposed to be. They care about what is done; and their experience of science truly runs the gamut; but more often than not, it is threatening, dull or expensive. Almost always, science is remote. Children see its effects and its products; but the makers of these, the controllers of creative scientific activity, are faceless intellectuals manipulating unimaginable resources.

Science museums and science centers have become remarkably effective at attracting the attention of children, but not very effective at involving children in science. They have become effective at filling children with marvel and excitement, but not very effective at filling them with thought. Partly this is due to the design of exhibits. The programming of most exhibits is limited to a few, repetitive activities. They are more reactive than interactive or transactive. They respond to a child's action, but do not change their programs. So attention is just as easily disengaged as it was engaged. The proximity of freestanding, limited response exhibits encourages rapid shifts of attention and hurried behaviors. The design of most exhibits is cognitively and physically remote. Children may activate them, but their workings are complex and often hidden or behind transparent barriers. Their operation can be observed but not manipulated. Often their scale of size and complexity puts them beyond children's ability to manipulate intelligently.

These features give the impression that science is completed technology; that children may appreciate its effects, but must remain mystified by its mechanisms. This impression persists even when the technology is intended to be merely a medium for the demonstration of some scientific principle or phenomenon. When the technology is not familiar or well understood, children have difficulty distinguishing qualities of the medium from the message. The attempt to make exhibits indestructible creates distance as well. Children are aware when design anticipates abuse, and frequently this encourages thoughtless, abusive behavior. The material of the exhibit is not incorporated into the ongoing interests and activities of the children. It remains a cognitively remote experience bite, outside the personalized structure of their comprehension.

Even in environments which are designed to support children's activities, science remains distant. In good schools children follow predictable, sequential procedures, duplicating activities which their predecessors have repeated every year before. Demonstrations are called experiments because the children do them. But very little about these activities is experimental. Children are aware that the outcomes are already known and predictable. They feel frustration or failure if their activity does not come out as expected. The pursuit of suggestion and alternative courses of action is severely restricted by rigid adherence to fixed procedures. Most unfortunately, this presentation of science as a procedure frequently discourages reflective thought, because its main concern is the direct application of a given method.

Teaching science as a process is a slogan whose utility has become distorted by its identification with procedure. While some aspects of science are characterized by procedures, there are other aspects which have no procedural regularities at all. From the perspective of children's development, the learning of scientific procedures, or of a scientific method, is not of much use in their construction of a scientific understanding of the world. The same can be said of other buzzwords in science education: hands-on, activity based, manipulative, discovery, inquiry, child centered, making learning fun, interactive. While each of these words point to some desirable characteristic of science education, they also lend themselves to interpretations so partial or so superficial as to actually obstruct the development of thought. They obscure the risks and uncertainties which must be accepted in scientific practice.

It is easy to forget that hands-on activities for children are often mindless. Manipulatives are often hopelessly abstract; manipulation can be meaningless. Unrelated factoids are discovered with no insight. Inquiry can be artificial, lacking personal interest. Child centeredness can turn in on itself, constricting the world, encouraging fruitless behavior. Making learning fun often makes it trivial or fleeting. Interaction is often merely reaction, precluding changes in the physical environment, other people or modes of activity.

But that is not all. Because of a cultural obsession with knowledge, science activities with children are almost always driven to make a point. They have as their goal or objective a measurable outcome, a memory bite, a fact or principle retained for recitation. There must in every case be an articulated lesson learned. So the process approaches to science education turn out to be disguised forms of learning science as established knowledge. They are child sensitive ways, humanly appealing ways, to facilitate the memory of facts and formulas. Not that this is unscientific. Some aspects of science are characterized by the need to remember much specialized information; there are other aspects for which whatever knowledge a person has is adequate. The presentation of science as knowledge can be even more effective than procedure at eliminating the opportunities for reflective thought, because its main concern is direct memorization of information. But from the perspective of children's development, the learning of scientific facts or principles is not of much use in their construction of a scientific understanding of the world.

It is often argued that these practices in science education are all distortions of science; that true science is characterized by the most desirable of human traits. So all sorts of people are criticized for misrepresenting the essence of science. But it would be more honest to acknowledge that science, as a human activity, is full of contradictions. The problem is not that teachers, school curricula, museum exhibits and the media miss the essence of science, but rather that science tolerates all these practices. It includes them. As an example of process, it frequently is said that science is a cooperative activity. But even children are aware that the practice of science is often ruthlessly competitive. Is it justified, then, to claim that science is essentially cooperative? Not at all. Science is as science does; especially to children. Science is both cooperative and competitive. Or as an example of knowledge, the concept of race is used by scientists in research and exposition. Yet there is a scientific perspective in which this idea has no credibility whatsoever. Is it warranted, then, to say that race is a scientific concept? It is and it is not.

It is not fruitful, for the education of children, to argue that science is essentially a kind of method, or a kind of knowledge. The useful question is not what is, essentially, science. This puts the focus in the wrong place. It usually results in characterizing science according to some of its most acceptable attributes, and then recommending that these be taught to children. But this misses entirely the developmental realities of children's lives. Children do not need an idealized version of what science could be or of what science has done, or of what some scientists might think, do and remember in some model situation. The useful question is to ask what aspects of science, in all of its messiness and contradictions, are of greatest value to children in the development of their own thought and behavior. Children are trying to construct and understand reality - to think - not to apply a method as they go through life or to acquire facts. Coincidentally, the experience of science is the experience of trying to make sense out of reality.

The construction of reality by children is a social process. This phenomenon is painfully neglected by contemporary educational thought. Research in cognitive development is usually interpreted and applied in an individual perspective, with regard to processes which occur for individual children. There is an inordinate concern for measurable and conclusive outcomes of learning. But these are cultural biases which misplace the liberating and educational functions of individualism and which exaggerate the need for simplicity and certainty. An individual perspective is a necessary constituent in understanding children’s learning, but it is painfully narrow and partial.

Social processes are messy. Consider the dynamics in any family or group of children. There is continual interaction, misunderstanding, temporary agreement, backtracking, starting over, divergence, distraction, compromise, readjustment of perspectives or attitudes, vacillation between thought and feeling, reevaluation. Nothing is ever finally settled. New issues, new conclusions arise all the time. All social processes are works in progress. They may pause, but do not end. Children are aware of these attributes in constructing their understanding of the world, and for the most part they are comfortable with them. As they grow older, they learn from adults to be threatened by them. They learn to be uncomfortable with uncertainty and to feel anxiety from tentativeness.

The construction of reality by science also is a social process. There are many strong affinities between this aspect of science and the ways in which children develop their understanding of the world. Science depends on human transaction. It relies on collaboration for its materials, its ideas and in its activity. It relies on confrontation and conflict for regulation and adjustment of its ideas and activities. It requires communication. Whatever clarity there is in scientific thought has arisen from the need to communicate it to others, and from the anticipation of their responses. There is no internal logic, no imperative implicit in science, which compels careful exposition. This compulsion derives entirely from the social demands of a social learning process. The practice of science has made conscious and explicit a social process for learning through experience; a process which is unconscious and implicit for almost all children and for most adults.

This process is social in three ways. It communicates the personal experience of individuals to others. The communicative transaction makes the personal experience an interpersonal or shared experience, allowing others to think and to act on the basis of it. As others participate in developing the experience, its social nature is deepened, refining and elaborating its implications for further thought and action. These implications constitute its significance as learning. Secondly, the suggestions which arise in inference have their sources in social history. More than most cultural activities, science incorporates its past into its present. It is extraordinarily attentive to what has been done before. Furthermore, the suggestions are influenced not only by previous science, but also by all of the cultural and social experience people bring into the present from their personal lives. Thirdly, the ways in which individuals represent scientific experiences to themselves have social origins. The communicative practices and interpersonal behaviors of social learning are absorbed by individuals and become intrapersonal resources for the interpretation and guidance of further activity. The circular relationship, which communication creates between interpersonal and intrapersonal experiences, makes it difficult to distinguish between them; and for the purposes of scientific learning, it is not often useful to do so.

All three of these aspects of science depend on the social media of conventionalized behaviors or practices and conventionalized modes of representation. The set of behaviors or practices has evolved over time to allow science to continue as a social mode of learning. Pressures on science from other cultural forces, political and economic, have influenced and complicated scientific practices. They also have influenced the ways in which scientific learning is represented. Language as a social mode is subject to vast ranges of interpretation and misinterpretation. Although, science must ultimately use language to communicate, it has devised other communicative forms which are structural, like charts and tables, or visual, like maps, illustrations or graphs, in attempts to communicate more clearly. It is commonplace to use the metaphor that mathematics is the language of science. But of equal significance to the learning process for most people, especially for children, models may be a language of science.

Many scientific ideas are expressed in terms of material models or model systems. These provide strong advantages for learning. The structure and behavior of models may be articulated in many modes: linguistic, mathematical, kinesthetic, spatial, or with metaphors from other kinds of sensory and imaginative experiences. Because models can take physical forms, they can be manipulated physically as well as mentally. This feature makes them more accessible to a greater variety of personal perspectives than ideas expressed exclusively in linguistic or mathematical terms. It also makes them richer in implication and suggestiveness for further possibilities of thought and activity evoked through inference.

Some of this suggestive richness arises because models tolerate contradictions and ambiguities which would be intolerable to logical forms. Some arises because models are open to differences in life experiences across cultures, gender, age and social class. Some arises because the aesthetic qualities of models keep them from being merely instrumental, so they remain open to interpretation, to many uses or possible directions, often yet unknown. Models refer imagination to a human scale of objects or processes which can be seen or heard, touched and manipulated by unaided eyes, ears and hands. Models can be played with, freeing creative powers from the constrictive pressures of goals or motivations external to the play. Scientists use models for these reasons; so do children. Children's play depends on the creation and use of models of objects and models of transactions with objects, people and systems in the world. Children's games are models of activity. Children use these models to create, experiment with, evaluate and modify their constructions of reality.

As children try to engage and understand the world around them, they use many of the same attributes which are found in science. This is not because children are naturally scientific. It is because both science and children draw on similar aspects of social transaction in order to learn. Children do not differ from scientists because they lack a procedure for ascertaining fact, or because they lack knowledge. The differences between science and children are in the degrees to which certain aspects of social learning through experience are emphasized, formalized and made conscious. The differences in degree embrace a similarity in kind. Here is the interface where fundamental aspects of science coincide with fundamental aspects of children's development.

Children think. They think hard. They think carefully. A fundamental aspect of children's growth is the need to construct and understand reality: to think. Many adults do not see this often, because so much energy is put into creating conditions for shaping children's physical or emotional behavior. Comparatively little attention is given to creating conditions for the development of reflective thought. As a culture, we are not very good at this. We rarely create environments where children are free to think, because reflective thought has no predictable outcome, no known consequence, no inexorable line to a foreseen conclusion. Reflective thought, in fact, is incompatible with most widely held notions of education. Furthermore, the development of reflective thought requires nurture, not merely freedom. Environments which nurture reflective thought are difficult to create. They require the materials and colleagues for activity which generates problems and questions, while at the same time providing the opportunities and impetus to suspend that activity in order to consider qualities of the materials and interactions, suggestions, and alternative possibilities.

The stimuli for thought form a continuum in terms of the degree to which their material contents and ways of dealing with these are within or without everyday experience or everyday concerns. On one end are practical needs, the carrying out of familiar or necessary activities with familiar objects. In most cases practical activities evoke thought only when they are interrupted or frustrated by some unforeseen circumstance. Toward the middle of the continuum, curiosity is a stimulus, for which the materials or objects may be familiar, but the notice of them or the purpose of thought is not for the sake of an immediate or practical need. Thought also may be evoked by curiosity when the ways of dealing with contents are familiar, but the materials are not. On the other end, thought may be stimulated by intellectual problems for which neither the material contents nor the ways of dealing with them are common in daily life. All of these stimuli, along the entire continuum, include emotional qualities and attitudes which influence the forms, contents and directions of the thinking they evoke.

The most comfortable stimulus with which to engage children in thought is curiosity. Some aspects of the situation are familiar, some are not. It is neither threatening nor boring. It does not appear entirely beyond comprehension, and practical (emotional and instrumental) needs are not an issue. Science tries to create environments with these qualities in laboratories. But there is more. Curiosity may stimulate thought, but curiosity does not develop thought. It might as easily lead to headlong action as to reflection. The problem is to create conditions within which children are encouraged, and find it easy, to inhibit their own activities and feelings long enough and often enough to think about them, to turn curiosity into reflection. Science is of great use in this regard, because it has formalized and habituated the periodic suspensions of goal directed activity which are necessary for making inferences.

Inference is that aspect of reflection which carries thought into the unknown. No one knows how this leap occurs. There are no rules about how to proceed. However, it is possible to describe features of the contexts in which inferences occur, and it is possible to make rules about these features. Inferences emerge during, or with reference to, some activity. Frequently, almost always for children, this activity involves the manipulation of material, or an interest in the aesthetic or manipulative qualities of material. When such an interest has no aim beyond itself, we call it curiosity. This interest in activity may occasion a new awareness. Something is noticed. If the feeling of interest is strong enough, suggestions arise which go beyond the information given by observation or memory.

These suggestions are the media of inference. The suggestions may not be articulated, but they are incorporated into existing purposes, ideas, habits, expectations, conditions and activities. They influence whatever occurs next. The activity, or the manipulation of material, is modified according to the suggestions. Some suggestions are borne out in subsequent activity. Others are abandoned because they lead nowhere interesting - they do not sustain interest - or because they do not work. There may appear to be a sequence in the inferential process, but this appearance is an artifact of description. The interplay among the various elements involved in inference is simultaneous and continuous. The movement among the elements occurs in no necessary order. It occurs in fits and starts, with no linear march to a conclusion. There are no rules for making the leaps of inference from the known to the unknown. It is a creative act.

While children do make inferences naturally and on their own, they require a great deal of help in learning to appreciate, expand and enhance the possibilities of inference. Science, through its historical development, has formalized or habituated certain attitudes and behaviors which bring to inference the possibilities of growth. If children can learn to use these attitudes and behaviors in their own activity, they will have understood something crucial about science. But even more importantly, they will have understood something crucial about using social resources to learn from experience.

Children have a tendency to act and to continue activity until it is interrupted by fatigue or some intervening event. Children also have a tendency to scrutinize, contemplate or muse and to continue doing so until interrupted by fatigue or some intervening event. But children are not very good at combining these tendencies. Science, however, can be very good at this. Some temporary, even partial, inhibition, some periodic suspension of activity is necessary for reflective thought. At the same time the activity can not be totally lost or else the thinking loses its ground and becomes pure fantasy. In the transaction between observant manipulation and inferential suggestion, each modifies the other, back and forth. This is a form of experimentation. During these oscillations there are little discoveries. They are found and lost and found again. This takes time; time which appears to be unproductive. But science can accept this inefficiency.

The periodic inhibitions also allow for some intellectualizing of what is being felt, of the emotional and aesthetic qualities of the experience. When this occurs, inference is opened to suggestions from many facets of a person's past and present experience. Perhaps the greatest human resource for thought is the transaction of life experiences in inference. The suggestions which inference carries into the unknown inherit characteristics from a person's history in culture. Gender, class, ethnicity, geography, even small episodes in people's lives, all infuse these suggestions. They are infused by what is remembered, by what is perceived in the present, by what is felt. Yet, for all the baggage which they carry, the suggestions of inference still have the quality of surprise. They are unexpected because the leap has separated them from the determinism of habit.

The development of this aspect of thought has been almost entirely neglected in the education of children, perhaps because it seems so complex, time-consuming, unpredictable and completely beyond control. These are precisely issues which science has dealt with throughout its history. At various times science has tried to control the ways inferences are made by using social forces to impose rules of procedure, or to define what counts as scientific, or to intimidate people into conformity, sometimes coercively, sometimes simply with the weight of data or authority. Science also has developed attitudes which leave the making of inferences beyond control, but which use social forces to broaden the input into these inferences, multiply the number of suggestions, and contextualize the consequences of acting upon them. These attitudes can help children expand the power of their own abilities to make inferences.

Six aspects of inference-making are enhanced by the attitudes and behaviors which science has habituated from social learning: the observation of phenomena, the resources available as input to suggestions, the contextualization of these suggestions, the manipulation of material according to the suggestions, the use of tools in observation and manipulation, and the tentativeness of knowledge and procedures. All of these aspects should be accounted for in an environment intended to develop children's abilities to make inferences. If the primary concern is the growth of children's thought rather than the canonization of science, then it is more important to use the environment to help children develop lasting attitudes and behaviors which enhance these aspects of inference rather than to acquire any particular information or to rehearse any particular technique regarding these aspects.

It is difficult to discuss the aspects of inference-making because of how thoroughly they permeate and influence each other. For example, observation is influenced by personal and cultural information, context, the material and its manipulation, the tools used, and by uncertainty. Similarly, the personal and cultural resources which inform suggestion are influenced by observation, context, and so on. The aspects of inference are not linear and do not form an activity sequence. It is impossible to anticipate the interplay among these influences and attempts to program their connection would be toxic to the process. Just as for the leap beyond the information given, the interplay among the aspects of inference is something for which there are no rules. Children have to be trusted to do this for themselves.

An environment supportive of the development of observation would be designed to slow down the pace of children's activity. Phenomena can be scrutinized only if they are lingered upon. They can be examined from various perspectives only if various perspectives are taken. The impulse to continue activity once it has begun often interferes with thoughtful observation. The voluntary control of impulsiveness has been formalized by science. Children are informally familiar with such control through their interest in the perspectives of others with whom they interact. It is a rare child who will not pause to consider some phenomenon pointed out by another. If the material is rich with effects, aesthetic qualities or manipulable possibilities, children will linger with it. Observation is further enhanced if the phenomena can be affected by transaction with the material in such a way that the observer's perspective is affected, giving rise to further suggestions for transaction. For this to occur there needs to be some continuity between the material, including ways of dealing with it, and the experience children bring into the transaction.

The need for continuity applies also to the scale and complexity of the material, which affects children's sense of control. If they are overwhelmed, observation is likely to end with the initial impression. Continuity allows children to contextualize the present observation within the framework of previous experience. This gives access to familiar modes of observation which can be utilized in the current activity. Access is improved when the material and its effects are observable through several sensory modalities. Tools for observation provide ways of manipulating or enhancing light, sound, temperature, motion, force and such, and ways of measuring these things to which our bodies are sensitive. The use of even simple tools vastly expands the types of observations that are possible. When participation in the environment is voluntary, when no external pressure sets up the expectation that some particular observation is desirable or correct, when there is opportunity and encouragement to share observations with others, then children can hold a tentative attitude toward their observations. This leaves them open to influence by subsequent experience and the experience of others. Observations in science always wait upon the observation by others of similar or different effects.

A wealth of observation is one source of input into the suggestions generated through inference. An environment supporting the development of inference would be designed to provide access to and to encourage the use of other interpersonal and intrapersonal resources. Not very often in education is a child's own past experience legitimized as a resource for reflective thought. But it is acceptable in science. Science activities can have continuities with the contents, purposes, conceptual frameworks and learning styles which children bring to them. This may stimulate an attitude from which children regard their experience as a resource for inference, and learn to consciously and systematically utilize it. Science as a social form of learning can not, in fact, reject any human resource that goes into making inferences, although in various contexts science has tried to do this. Intuition, imagination, hunches and passion have equal status with data, logic, tradition and authority as sources of input. Science can be very fussy about the outcome of inference, but not about the resources used to stimulate suggestion.

A vast resource for suggestion is interpersonal. Science has formalized collaboration. Part of the learning advantage of collaboration is that it gives the participants access to one another's experience. In this way life histories are drawn into the present, and of particular significance in this regard are attitudes which are sensitive to differences in cultural perspectives and social conditions. The content of suggestions arising through inference is enriched by these differences. As collaborators interact, their perceptions, feelings, skills and suggestions are drawn into the activity. These influence observation, the application of suggestion, the manipulation of material, the use of tools and the degree to which knowledge and procedure are held tentative.

Scale and complexity are issues for children in collaboration. The group needs to be small enough, and the project manageable enough, that the children can be attentive to one another's contributions. An advantage of collaboration is that invariably the participants' impulses will conflict. A consequence of such conflict is that activity is temporarily suspended. If interest in continuing the activity is strong, and the milieu is cooperative, the suspension becomes an opportunity for thought, and for the consideration of others' perspectives. This use of interpersonal conflict for the elaboration of thought can become a model to children for the use of conflicting intrapersonal impulses or ideas.

The development of suggestions arising in inference occurs through contextualizing them. In this aspect of reflective thought, conflicting impulses, observations and ideas are incorporated into existing conditions, purposes and frameworks to test their effects. It is a kind of mental experimentation. The pauses in activity are used to entertain alternative suggestions, to consider alternative courses of action and their possible consequences. Ideas are related to each other. Relationships are imagined or temporarily constructed among things or events that previously seemed unrelated. Metaphors and models are made.

All of the aspects of inference are affected by this. For example, observation clearly is affected by what observers think they are looking for. Manipulation of material is affected by the anticipation of consequences and by the purposes in mind, or by the conceptual framework within which it occurs. Science has formalized and habituated the entertaining of alternative suggestions, and speculation about the various possible outcomes of these suggestions. It has formalized also the contextualizing of suggestions within the conditions and purposes of ongoing inquiry, and also within the framework of inherited theories, models, historical trends, and the accumulated data, results and speculations of other investigations.

A scientific environment can help children develop the attitudes of openness, patience and honesty required for the speculative aspect of inference. Children have a tendency to act on the first suggestion that comes to mind. But they can learn to use the suggestions of others, or to search the environment, the material or their own past experience for alternative suggestions. They can learn to use these suggestions in the development of purposes which guide activity. Since all the aspects of inference are synchronous, the development of purposes for the activity occurs as an ongoing feature of the activity. Reflection turns impulse into purpose. The impulses to take particular action, and the suggestions which stimulate them, are continuously transformed into or conformed to ongoing purposes. Purposes are modified as a result. If children are open to these changes, they end up accomplishing something they did not start out to do. The course which activity actually takes is unanticipated. The outcomes are unexpected.

Children have a tendency to jump to conclusions as well as to act on impulse. A scientific environment for children can facilitate the preliminary relation of ideas, things and events. This can be done with material that is rich in possibilities for manipulation and interpretation, and that can be incorporated into many purposes in many ways. It can be done with models of things, events or systems which can be played with, modified and utilized in activity. Of enormous importance to children in facilitating the relation of ideas is the opportunity to utilize all of their sensory modalities. The use of visual, auditory, tactile and kinetic modes not only expands the variety of input, it also allows the formation of cross-modal metaphors. Such metaphors open funds of experience and frames of mind which otherwise would be overlooked or inaccessible. Through the modalities and metaphors they become available as resources for thought. An attitude supporting a similar synergy has developed in the interdisciplinary activities of science.

Perhaps near the heart of science, and certainly at its emotional core, is the manipulation of physical material according to the suggestions of inference. It is unlikely that science would have evolved as a vast social enterprise were it not for an interest in the manipulation of physical objects. Even highly theoretical activities in science are grounded in this interest. Educational practice does not usually consider manipulation to be an aspect of thought. Usually, manipulation is considered as something to be thought about, or as something that provides experience for thought. But in the process of inference-making, manipulation plays as important a role as observation or memory or imagination. Relentless mental activity can be as thoughtless as relentless physical activity. Some temporary, even partial, inhibition, some periodic suspension of mental activity is necessary for reflective thought. The pauses provide opportunities to act on the basis of suggestions arising in inference. In science, this activity usually means manipulation of some physical material. It means much the same in the arts.

An interest in the aesthetic qualities of material and the aesthetic effects of manipulating material are fundamental features of children's behavior. An environment supporting the development of inference would be attentive to and collaborate with this interest. Materials would be available that have intrinsic aesthetic appeal and that have special potential for aesthetic manipulation. Such material holds interest and maintains the interplay between physical and mental activity. It also keeps motivation in the present and within the activity itself. The manipulation of material applies not only to curiosity about effects or experimentation, but also to the creation or construction of objects, devices, effects and events. If in the course of such activity are produced aesthetically interesting sounds, sights, shapes, color, movement or interactions, the depth and breadth of experience is enhanced.

The role of aesthetic sense throughout the history of science has been well documented. Often it is described as a source of criteria in shaping theories or models. But its influence is equally strong with regard to qualities of the material, the ways material is manipulated, and to the shaping of apparatus and tools for manipulation. Neither science nor inference would lead to learning without the manipulation of material. It creates new opportunities for observation and altered contexts for the relation of ideas. It manifests or reveals the consequences of suggestions. It tests how the suggestions work, how they affect activity, how they fit the behavior of things. Experiments are manipulations of material according to the suggestions of inference. All the qualities of the experimental experience feed back into the process of inference, providing new resources for suggestion. Everything that is called a conclusion in science is a consequence of manipulating material.

Tools not only provide a means of manipulation, they also suggest ways of manipulating material that otherwise would not occur. The history of science is also a history of tool making and of tool use. Tools are an indispensable part of the development of scientific thought, and an integral aspect of inference-making. It is arguable that were it not for the use of tools, inference would never have developed a central role in reflective thought. Using a tool is like putting a thought between oneself and an object. It opens new dimensions of observation. It gives control over impulses. It shapes purpose. It allows suggestion to be elaborated and tested.

Children are fascinated by the use of tools. They are aware of how empowering a skill with tools can be. An environment which supports the development of inference in children must provide access to tools. The empowering and liberating effects of tool use depend on a balance with the other aspects of inference. Tool use can become rote and thoughtless, just as manipulation or the connecting of ideas can become so. Thought can be enslaved to methods or techniques. But if all of the aspects of inference come into play, they correct and modify each other. They never ossify and settle into irreversible habit. They retain a tentative quality.

All of the conclusions of science are tentative. All of its facts, rules, laws, procedures, even its objects, are tentative. Perhaps the most significant achievement of science is that it has formalized this characteristic of social transaction into a principle of learning. It fits excellently the way in which children go about their construction of reality. It applies to all of the aspects of inference: to observation, resources, contextualization, manipulation and tool use. It leaves an open mind. Children may temporarily cling to a favorite idea or practice, but they usually are willing to reconstruct these, given evidence, social support and time enough. Science can help children with these givens, and can help to bring the tentativeness closer to the present.

In many of its manifestations the result of scientific activity appears to be unambiguous and final.

Science applied in technology gives an illusion of finality. A television set works; it does not change. There appears nothing tentative about it, until it breaks. But then the knowledge that made it does not appear tentative. It can be fixed. The results of science are formulated in conclusive, symbolic terms; they are tested, widely held and used, consistent with past and present beliefs and practices, predictive of future results. What could be more certain? Yet for all the weight suggesting certainty and finality, these results are uncertain and temporary. The television works because it is good enough. The knowledge that made it is good enough. Over time, it will change. Good enough ought to be another principle of learning.

Although there is much practice to the contrary, there are no conclusions in science. There are only temporary summaries of work in progress. There are only temporary solutions to problems; temporary answers to questions. If science can help children feel comfortable with this tentativeness, if it can affirm their inclination to remain open to change, if it can infuse their inference making with this attitude, then it will have enabled them as thoughtful, human beings. An attitude of tentativeness makes it possible to entertain alternative suggestions, to withhold judgment, to see things again and expect to see things differently, to anticipate consequences and accept those that are unexpected. It sustains hope, because there is always a next step, a new suggestion, a new direction. It makes possible the continuous reconstruction of experience.

The continuous reconstruction of experience through reflective thought ought to be the best hope of science education for children. Reflective thought takes time. It cannot be hurried. Most educational settings have neither the environments nor the patience necessary for the development of inference in reflective thought. The environment needs to be rich in material supporting the various aspects of inference. But it also needs to create a milieu which encourages children to linger, to leave expecting to return, to collaborate, to use all of their capacities in conscious ways. Participation needs to be voluntary. Children need to be engaged in maintaining the milieu as well as in accepting behaviors which support it. It needs to free children from external pressures, from the oppressive expectation that they must remember something in particular and that they will be judged by this expectation. It needs to tolerate inefficiency, unproductive turns, trying things over, wasting time. Children's thought is often richest when they appear to be wasting time. The environment needs to be truly transactive, which means that it supports the interplay between interpersonal and intrapersonal activity, and also that it can change and be changed by the activity occurring within it. Through transaction, both the children and the objects of the environment are somewhat different than they were before.

Science is a culturally developed set of attitudes and behaviors for learning through experience. These are emotional, intellectual and physical tendencies for transacting with the world through certain features of social life. Some of these attitudes and behaviors can be especially useful to children in the growth of their capacities for reflective thought. The development of lasting attitudes, behaviors, expectations and preferences are more important in this growth than the contents of any knowledge or the elements of any procedure. They are more important because, ultimately, they matter more in the future. They shape the frames of mind through which experience is reconstructed. They determine what is learned. What a child takes out of an experience matters less than what a child brings into a future experience. What is taken out is fragile; it might not last until tomorrow. What is brought into the future, has endured; it shapes the form of content. Children can infuse their activity with exuberance and joy. If we can help them carry, into the future, attitudes which open reflective thought, we will have contributed a means for the incalculable pleasure of discovering something entirely unexpected.