Models and Archetypical Phenomenon as the Basic Organizers of Elementary and Middle School Curriculum

Bernie Zubrowski
Children's Museum
300 Congress Street
Boston, Massachusetts 02210

Models of all kinds have been favorite playthings with children for a long time. Whether of cars, trains, machinery, animals or humans they engage children for hours. Adults also can become quite involved constructing and playing with models. As one example there is a group of men who meet at a MIT gymnasium once a month to fly rubber band powered model airplanes. This is only one example among hundreds of adult type activities with models. There is an inherent fascination in models whose use serves to fulfill personal needs at several levels. They are more than playthings filling the free time of individuals. They fulfill emotional as well as cognitive needs of individuals.

It is especially the cognitive role of models that has been long recognized by teachers and curriculum designers and put to use in the role of pedogogical tools. This is especially true for the teaching of science. Scale models of structures, the solar system, the human body are the most recognizable examples. Less frequently used and not acknowledged as such are systems which model electrical circuits or the dissection of small animals as analogues for human anatomy. Then there are other kinds of models such as the agatation of a ball bearing on a vibrating table representing the motion of atoms serving as a concrete manifestation of the kinetic theory of gases.

Although there isn't a large body of research which justifies the use of such models in teaching science, practical experience in the classroom indicates to teachers that they are helpful and in fact at times perform a crucial function for students in learning basic concepts in science. Whether it be scale or analogue models or the more abstract heuristic ones or formal science, their important role has not been sufficiently acknowledged. Yet, a survey of present day textbook and major elementary curriculum programs indicate that few mention the role of modelling in scientific thinking. (A recent exception is the program Search for Solutions (1980). The prevailing pedagogy dominating science education presents concrete experiences mostly as illustrations or exemplars of scientific concepts. Reasoning by analogy is not part of the learning process, nor are the concrete experience seen as templates for assimilating future experiences as it relates to a scientific framework.

There was one program which had an implicit concept of modeling in the choice of its topics and in its design of experiences. This was the Elementary Science Study. Working with the topics of this curriculum in the classroom has suggested to me that some of them can be changed to make more explicit the role of modelling in science, and thereby enrich the learning of students. It is my contention that a combination of topics from this program as well as other intrinsically interesting phenomenon such as bubbles or toy tops could be thought of as archetypes for related phenomenon. They could serve as the experiential foundation upon which fundamental concepts of physical science can be developed and act as the basic reference for the more abstract concept in post elementary science courses. The remainder of this paper will illustrate some specific ways of how this can occur and develop a rationale for taking such an approach.

Elementary Science Curriculum and the Role of Models

During the 60s and 70s the National Science Foundation funded several major programs to develop elementary science curriculum. Each program was different in its overall conceptual approach even though they incorporated some of the same concrete material and phenomenon into their programs. Thus Science, A Process Approach used batteries and bulbs to promote such skills as observation and recording data while the Science Curriculum Improvement Study used the same material to develop the broad concepts of systems and interaction. These and derivative text book programs gave heavy emphasis to process skills and logical thinking. At that time such an approach was described as emphasizing process over content. The one major program that had a somewhat different approach and emphasis was the Elementary Science Study. Modular in structure it allowed the classroom teacher to expose students to fundamental phenomenon as the others programs did but each phenomenon was investigated in-depth. There were eight to twelve lessons with batteries and bulbs, not one or two. Process skills were developed, but there was also an emphasis on exploration for its own sake. Implicit in the choice of phenomenon, and the design of the activities was a modelling of how real scientist might go about investigating the phenomenon. Also, implied was the concept of the phenomenon itself acting as a model for other systems in the natural and man-made world. Thus, the unit called "Microgardening" which was about the investigation of molds could be thought of as an example of how to investigate microorganisms and how to learn about their behavior.

Because different individuals developed each of the topics and the program extended over a number of years, there was wide variations in how the teacher's guides were written. However, there was a shared philosophy which gave high priority to children's need to explore phenomenon in a concrete manner, but viewpoints did vary on how the phenomenon was to be presented. Nor was there an attempt to explicitly suggest that each of the phenomenon were archtypes for other related systems and materials.

It was after my work at the Elementary Science Study and the African Primary Science Program, which adapted ESS topics for African schools, that I began to see that some of the topics could be recast into a different framework. The basic approach of hands-on, extended investigations remained the same but the problems presented to the students were different. One of the first topics where it occurred to me that the concept of models and modelling could be used as an organizing principles was in the unit called "Structures." It was my experience in doing activities from this unit that students usually built houses and inevitably had problems keeping them upright. Most students quickly discovered that diagonals along the sides of the house provided rigidity and support. Students also liked to build towers and bridges drawing upon what they had seen in their immediate environment. Diagonals are also used in these structures to form triangular arrangements to give stability and strength. It occurred to me that a nice sequence of activities would result if students were challenged to build houses, roof tops of houses, bridges and towers focusing on how triangular arrangements gave useful structures. Along the way students could enhance their planning and analytical skills as they would have done with other kinds of activities with drinking straws and pins. Recast in this sequence and giving emphasis on triangular arrangements the learning experience would be much richer. If one refers to the literature of structural engineering, it will be found that many modern structures can be reduced to a few fundamental systems. The triangular truss system is one of them.

The house made by the student with drinking straws and pins can function as a model in several different ways and levels. In a very concrete manner it a can function as a scale model for a real house. So-called balloon-frame houses were constructed in large numbers at one time in a America, and many are still standing. The scale model drinking straw house can help the student understand how and why these were constructed. This same model, especially by focusing on the structure of the roof can act as analogue models for a variety of other building and structures such as factories, airplane hangers, and certain kind of bridges. At a more abstract level it allows the teacher to introduce the physicist's conception of force and to talk about in a concrete fashion equilibrium of forces. In this sense one can think of the model house as a archetypical structure. It doesn't include all kinds of structural systems, but it does give the student a relevant concrete situation upon which concepts of increasing abstraction can evolve and provides a conceptual template by which they can begin to analyze and understand a wide variety of other structures.

Models in Real Science

Since one of the goals of a good science curriculum is to provide students with conceptual tools that will help them understand the natural world, it would seem counter-productive to have them spend their time investigating specific concrete phenomenon in an extended manner. To justify such as approach we need to consider what role models or modelling plays in scientific thought and determine in what way models help the students assimilate new experiences.

In the literature reporting about research in science models of all knids are frequently invoked. In the physical science they are most often mathematical in nature while biological ones are usually a specific organism or special enviroment. It is only in recent years that wrtiers have began to examine their role in scientific thinking.

Max Black in his book Models and Metaphors (1962) devotes part of it to examining the role models play in science. After considering scale and analogue models and their role in science he then elaborates upon the use of mathematical and theoretical models in science. Using James Clark Maxwell's work in electromagnetic theory as an example he cites Maxwell's own comments regarding the role that modelling played in developing his theories.

> "The first process therefore in the effectual study of the science must be one of simplication and reduction of the results of previous investigation to a form in which the mind can grasp them. The results of this simplication may take the form of a purely mathematical formula or a physical hypothesis. In the first case we entirely lose sight of the phenomenon to be explained; and though we may trace out the consequences of given laws, we can never obtain more extended views of the connexions of the subject. If, on the other hand, we adopt a physical hypothesis, we see the phenomenon only through a medium, and are liable to that blindness to facts and rashness in assumption which a partial explanation encourages. We must therefore discover some method of investigation which allows the mind at every step to lay hold of a clear physical conception, without being committed to any theory founded on the physical science

> from which that conception is borrowed, so that it is neither drawn aside from the subject in pursuit of analytical subtleties, nor carried beyond the truth by a favourite hypothesis."

Maxwell set out to place Faraday's findings about electric charges or magnetic dipoles into a theoretical framework that would be represented mathematically and therefore justify Faraday's claim that action arose from lines of force instead of charges or poles. According to Brian Gee (1978) Maxwell adapted an already existing theory of hydrodynamics to substantiate Faraday's claim.

What is more interesting is his use of mechanical model to represent other known electromagnetic and electrodynamic phenomenon. Gee, Black and Hesse (1958) take the position that analogues in models serve a heuristic function. "They act as tools which help the scientist to represent and/or articulate a new idea." The more concrete phenomenon of vorticies in fluids gave a clear physical conception of the less tangible magnetic and electric fields. Secondly, Gee takes the position that the mechanical models of electric and mechanical fields also "served to communicate a developing idea to an audience of mechanical thinkers." Considering these statements from a pedogical point of view we have what I would propose as characteristics of a good science curriculum. We want students to develop a clear physical conception of the phenomenon they are investigating, and help them represent it a manner that will enable them to begin the reconsiliation of their own native theories with those of formal science. Experience with concrete phenomenon designed to act as model situations could accomplish this goal.

Models as Metaphors

There are differences of opinion among historians and philosophers about the role of modelling in the development of scientific theory. Whether their role will be fully recognized or not, it is apparent as Gee has pointed out that they serve a very useful pedogogical function. They are effective methods of representation and communication.

If modelling were to become an important part of science curriculum, we need to examine how they function on a cognitive level. In order to do this, models have to be placed in a broader context. Models act as a means of representing complex or poorly understood phenomenon in a simple way. Salient characteristics of a well known phenomenon are mapped on to those of the less well known. Analogies are developed between the two phenomenae so that a framework is established for assimilating this new situation. The kind of thinking involved here is metaphoric thought in the broadest sense of the term.

In recent years there has been much written about metaphor mostly from a linguistic point of view. Few writers have examined the role of metaphor in science. At one time Black, whose views on metaphor have often been cited, saw metaphors and models as separate, but in a recent paper (1979) stated that, "Every metaphor is the tip of a submerged model." Having realized the relations of metaphor in light of recent writing of other authors he feels there is a tight connection between models and metaphors.

In addition to this changing conception regarding models, there is also beginning to emerge attempts to examine the cognitive role of metaphor.

MacCormick in his recent book, A Cognitive Theory of Metaphor (1985), addresses this issue directly. In his introduction he summarizes his approach. "Viewed internally, metaphors operate as cognitive processes that produce new insights and new hypotheses. Viewed externally, metaphors operate as mediators between the human mind and culture. New metaphors change both the ordinary language we use and the ways in which we perceive and understand the world."

His distinction is important and relevant when talking about the role that models play in teaching science. Maxwell's use of fluid models for electrical phenomenon illustrates how they can change the way scientists view a phenomenon. For students, models generate insight which helps them reconcile their own intuitive formulations with the formal concepts of science.

Most literature on metaphors examine its role in language, and discusses its function and how it works using the framework and concepts of linguistics. Among those few who have examined its role in education, Ortony comments are most relevant to the argument presented here. He proposes that there are three general characteristics of metaphors that facilitate learning.

1. Compactness- metaphors work by transferring chunks of experience from well-know to less well-known contents.

2. Vividness- metaphors permit and impress a more memorable learning due to greater imagery or concreteness.

3. Inexpressibility- certain aspects of natural experience are never included in language.

These three statements could as well be applied to models. The following sections examine how they apply using the example of drinking straw structures.

Inexpressibility in Metaphors and Models

In a metaphor one kind of object or situation is being juxtaposed and compared to another. The object to which something is being compared is assumed to have characteristics familiar to us. The relationships among these salient characteristics can form a framework by which we view this other object or situation. This relationship of parts is often not expressed in words. Consider a situation in which the teachers is attempting to have students internalize the concepts of tension, compression, and the balance of forces in a building or bridge. The physicists gives formal definition to each, and represents them in a mathematical manner. Balances and scales can measure forces, but in one sense these indictators are still representations. A student viewing a static framework of drinking straws can't see straws pulling or pushing against each other. How can they understand these actions in a personal framework? Forest Wilson (1968) in his book, What it Feels Like to be a Building came up with a nice way of making such forces more tangible. Various kinds of structures in his book are compared to men's bodies stretched or piled up on top of each other. Thus, a lintel is represented by a man bridging the gaps between two posts, and an arch is represented by men piled up on each other. Drawing on our own experience of what our bodies feel like when stretched across two chairs or buried under a pile of other people, we can experience within ourselves through our haptic sense what these structures feels like. Such sensations are not easily described in words, Wilson mainly by the visual pictorial mode suggest this basic hapltic experience.

Vividness in Models

As Ortony and other authors have pointed out metaphors generate rich imagery. In the context of science curriculum for children and beginning learners this has great revelance because of the concrete nature of their learning. Among the many descriptions of the concepts of image, Suzanne Langer (1967) has defined it in a way that fits well with our purpose here. She states, "An image does not exemplify the same principles of construction as the object it symbolizes but abstracts its phenomenonal character, its immediate effect on our sensibility or the way it presents itself as something of importance, magnitude, strength or fragility, performance or transience, ect. It organizes and enhances the impression directly received." The vividness of metaphors arises out of close association with concrete experience. Consider the comparison being made in Wilson's book in which he compares stacking of bodies to specific kinds of structural system. The forces felt within our body is immediate and direct. The student can easily recall what his or her body felt like when buried under a bunch of others while roughhousing in the playground. Similarly, the experience of the strain in the leg and back muscles when one person is carrying another on their shoulders is another experience for anchoring such concepts as tension. The haptic imagery that results in comparing human bodies to structural systems is rich in associations.

Such imagery as Langer points out readily becomes metaphorical because, "they are our readiest instruments for abstracting concepts from the tumbling streams of impressions." (Phil. in New Key. p117)

Compactness in Models

The imagery that arises in metaphor also results in large amounts of information of the one reference being transferred to another. Langer (Mind, p.60) points out- "the high intellectual value of images lies in the fact that they usually and perhaps always fit more than one actual experience. We not only produce them by every act of memory (and perhaps by other acts) but we impose them on new perceptions, constantly, without intent or effort, as the normal process of formulating our sensory impression and apprehended facts. Consequently, we tend to see the form of one thing in another---"

It is interesting that a current architectural trend in designing tall building is to place a "hat" on top. Some of the new tall buildings in downtown Boston have a triangular roof top serving as more a decorative rather than a functional value. We seem to identify our own bodies with even these very tall building, or see them as elongated houses. Likewise, to say that a roof of a house is like a bridge is to suggest that there is an analogical correspondence in the comparison. Functionally, the former protects the inhabitants of a house while the latter allows vehicles to cross a river. However, both span a gap and support weight other than the members of the structure. The structural framework of both can be viewed at an abstract level as performing a similar function.

In designing curriculum which focuses on structures one could either start off by defining the concepts of force, tension, compression, etc. Then, each of these concepts would be illustrated with different kinds of structures. The result are abstract concepts loosely connected to concrete experience imposed on these experiences. On the other hand, students could do an extended investigation of a model house during which these same concepts emerge naturally through pointed discussions and carefully crafted challenges and discussions which focus on key features of the structures. The house acts then as a organizing scheme at a concrete and conceptual level providing context for these concepts. It also can act as a structural archetype for which one can begin to understand other related structures.

Archetypical Phenomenon as Fundamental Organizer for Science Curriculum

Given all the information and concepts that according to some authorities should be covered in a science curriculum, it would seem to be very costly if not extravagant to have students spend several weeks building model structures. Does it really take that long for them to understand why a structure remains standing . If this were the only goal it perhaps is extravagant. The point here is that they are learning more than this. Whether analyzing model houses, bridges or towers they are learning in a concrete fashion about such concepts as force, tension-compression and the equilibrium of force. But even more important than these concepts is that they gain a conceptual template by which others ways of experience can be framed, analyzed and understood. This can be be a powerful method of learning and is in fact one method by which knowledge is extended. Stephen C. Pepper (1942), who has been frequently quoted about this fundamental process describes this method as it relates to what he calls world Hypothesis,

> "The method in principle seems to be this: A man desiring to understand the world looks about for a clue to its comprehension. He pitches upon some area of common-sense fact and tries if he cannot understand other areas in terms of this one. The original area becomes than his basic analogy or root metaphor. He describes as best he can the characteristics of this area, or, if you will, discriminates its structure. A list of its structural characteristics becomes his basic concepts of explanation and description. We call them a set of categories . In terms of these categories he proceeds to study all other areas of fact whether uncriticized or previously criticized. He undertakes to interpert all facts in terms of these categories. As a result of the impact of these other facts upon his categories, he may qualify and readjust the categories, so that a set of categories commonly changes and develops. Since the basic analogy or root metaphors normally (and probably at least in part necessarily) arises out of common sense, a great deal of development and refinement of a set of categories is required if they are to prove adequate for a hypothesis of unlimited scope. Some root metaphors prove more fertile than others, have greater power of expansion and adjustment. These survive in comparison with the others and generate the relatively adeqate world theories."

If we could substitute basic phenomenon for what he calls common-sense fact and replace world theories for the various subdisciplines of science, we have a statement of what should be the major goal of any science curriculum. It is impossible to communicate to students all the factual and conceptual knowledge that now exists in all the sciences. One approach over the last twenty years in attempting to address this problem was to emphasize process over content. It is my contention that these are not easily separated. Process skills which do not arise in a meaningful content will not be retained. Direct experience with intrinsically interesting phenomenon structures to make salient their archetypical properties can provide that context.

By intrinsically interesting phenomenon I mean systems or objects which in and of themselves incite active exploration. Besides the one example of model structures there are other objects which have long been favorite playthings of children. Closely related to model structures are bubbles. Peter Pearce (1978) and Cyril Smith (1954) consider bubbles and various kinds of bubbles arrays as an archetype for a wide variety of natural and man made systems. Toy tops, and related spinning toys, appear to be simple devices but attempting to understand their operation takes one deeply into the physics of rotational motion. Food color, simple liquids or solid objects falling in a container of water or other liquids as seen in many contemporary adult toys could be looked upon as crude models for studying movement in fluids. There are other materials familiar to students which could also be thought of as archetypical phenomenae.

To think of curriculum in these terms is to propose a completely different pedagogical approach than that which prevails in contemporary science education. What I am proposing is that instead of the traditional division of light, heat, sound, energy, electricity, students investigate and discover properties of mirrors and lenses, make ice cream in a coffee can, construct and experiment with model wind mills and water wheels, and design simple circuit with batteries and bulbs. The concepts would arise from the students interaction with the materials guided by the teacher. A further implication of this pedogical approach is that instead of a spiral curriculum by which students comes back to the same concepts as they make their way through school, they instead come back to the same phenomenon and develop a firmer grasp of what is happening through increasing effort to represent it in a more quanitative manner and in a more abstract form. Given the reluctance teachers have continually shown in the teaching of science this approach may appear to be totally unrealistic. This is indeed a great problem with any approach that encourages teachers to introduce real phenomenae into their classroom. However, it has been my experience in teacher training programs that they are very receptive to this kind of pedogogy. Presenting them with materials that appeal to them on a personal level- i.e. the phenomenon has aesthetic appeal, and relating it to other areas of their life gives them a sense of accessibility. Nevertheless, most textbooks and curriculum guides continue to promote another kind of pedogogy. It may be years before an approach based on archetypes and intrinsically interesting phenomenon takes hold. Until it does or until science educators give greater recognition to the role of metaphoric thought in developing and imparting scientific knowledge students will continue to struggle, fail and be turned off to science.