NATURAL LEARNING

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ABSTRACT

This memo reports the results of a case study into how children learn in the absence of explicit teaching. The three subjects, an eight year old, a ten year old and a thirteen year old were observed in both of two experimental micro-worlds. The first of these micro-worlds, called the Chemicals World, included a large table, a collection of laboratory and household chemicals, and apparatus for conducting experiments with chemicals; the second, called the *Mork and Mindy* World included a collection of video-taped episodes of the television series *Mork and Mindy*, a video-tape machine and an experimenter with whom the subjects could discuss the episodes. The main result of the study is a theory of how children's interests interact with knowledge embodied in their environment causing them to learn new powerful ideas. An early version of this theory is presented in chapter five.

For my teacher

Seymour Papert

CONTENTS

1. Knowledge, Emotions and Learning

1.1 Knowledge and Emotions

It is common to divide psychologists into two large groups, one interested in knowledge and intelligence, and the other in emotions. The first group studies such subjects as inference, memory, perception and language; the second studies attachment, aggression, motivation and identity. The most obvious application of the first group's research is in education; the most obvious application of the second group's research is in psychotherapy. The most famous member of the first group is Jean Piaget; the most famous of the second is Sigmund Freud.

Psychologists often try to study knowledge in isolation from emotions and emotions in isolation from knowledge. Sometimes we assume that our subjects' knowledge and not their emotions determine the results of our experiments; other times we assume just the opposite, that emotions and not knowledge produce our observations. History has demonstrated that this assumption of independence can be a very useful simplification. It has enabled us to gain important insights about knowledge on the one hand and emotions on the other.

Nevertheless we know that in reality knowledge and emotions are not isolated from one another. Knowledge can be emotionally highly charged; emotions can be modulated by increased knowledge. If knowledge and emotions do interact, inevitably their interaction should affect people's behaviour. It therefore follows that human behaviour can be better understood from studying these interactions.

In the past, the psychology of knowledge and the psychology of emotions have usually been treated as autonomous subjects. But since knowledge and emotions do interact, it should be possible to find a connection between these two branches of psychology. One goal of my research has been to describe a relationship between knowledge and emotions.

More specifically, I have investigated how an understanding of such a relationship can shed light on one of the most important problems in psychology, the problem of learning. There are few

subjects which have produced as little consensus among psychologists as this one. Most experts would agree that reinforcement and imitation both play some role in learning. But beyond this simple assertion, there is little consensus. In fact, most psychologists find it difficult even to imagine how most mental activities could be learned. Cognitive psychologists cannot explain how language or mathematics are learned; personality psychologists do not know how tolerance and compassion are acquired. It is hard to deny that learning is one of the least understood psychological processes.

Although learning has been studied as extensively as any problem in psychology, it has continually proven most intractable. The limited success of earlier research should justify now an unusual degree of daring. Since we have been unable to explain learning on the basis of our usual premises, we should finally be willing to try some unusual assumptions.

Between May, 1979 and January, 1980, I conducted a case study of three children in the process of learning. I saw each child one hour a week for approximately 12 weeks. For half the sessions, they watched and then talked about an episode from a popular television series; for the remainder, they experimented with a collection of chemicals. During the study, all three children acquired new concepts and new skills. My analysis of their behaviour traced the decisive events which contributed to the growth of their knowledge.

The premise that knowledge and emotions interact has been an unusual assumption in most psychological research. Researchers have avoided this idea not because it appears untrue but rather because it has seemed unhelpful. Thus the assumption of interaction remains a plausible but neglected one. This is precisely the kind of lead which should be tried in attacking a particularly difficult problem. It is this premise which underlies the present analysis of children's learning.

1.2 Learning as an Emergent Effect

A recurring theme throughout this thesis is that learning is an emergent effect. People do not learn because they are trying to learn or because someone else is trying to teach them. Nor is the content of their learning determined necessarily by their intellectual ambitions. I see learning as an inevitable byproduct of ordinary human activity: as people act, they cannot help but learn something. Of course not all learning is especially useful; we learn bad habits as well as good, trivial ideas as well as deep ones. The sophistication of our intellectual values, as well as the judgment and skill of our teachers, can signifcantly influence the adaptiveness of our learning. But the subject of my research is how any learning, and not merely adaptive learning, is possible. My claim is that people learn not because they are trying but because they cannot help it.

I wish to relate an incident to illustrate how learning can emerge. During the fifth week of my research, a ten year old named Toby learned to store gases in glass beakers, just as one might store liquids. A careful analysis of Toby's behaviour would reveal a long sequence of events which led gradually to this discovery. However you can grasp the structure of Toby's learning most easily if I describe just a few essential facts.

Toby's discovery may be traced to two pre-existing interests. Since the opening session, Toby had liked to make a gas which he called "my purple smoke." After discovering it accidentally when heating a mixture of table salt, sulfur and sodium iodate, Toby undertook a series of experiments using this gas. Many of these experiments involved spilling the gas. He would dump it over such objects as a piece of paper, a table top or his hand to see the resulting stain. A second interest, to develop only during the third session, was to pour liquids between beakers. Toby liked to prepare mixtures and then combine them in varying ratios.

During the fifth session, Toby's interest in spilling purple smoke combined with his interest in pouring liquids. This week, Toby spilled his smoke not onto a flat surface but into a beaker.

When the smoke stayed in the container, he proceeded to pour it into a second beaker, just as he would previously have poured a liquid. During the same session, Toby stored a second gas in a beaker. Since this second gas was less dense than air, he had to pour it not down into a fresh upright beaker but rather up into an upside-down beaker.

You should note that this episode included some experiences which we would normally call emotional, and others which we would call intellectual. *Interest* is the emotion which contributed most obviously to Toby's learning. Toby thought of pouring purple smoke because he was already interested in pouring and in purple smoke. But interest alone was not sufficient to produce learning. To the objects of his interest, he applied intellectual operations. First he *combined* his two interests into one act, the pouring of the purple gas. Second he *varied* his action when he poured one gas in place of another.

Throughout my research, I continually found that interest was an important emotion in children's learning and that combination and variation were important intellectual operations. Interest served to focus children's attention on a few salient objects in an otherwise confusing and complex environment. Combination and variation served to expand their interests to include more complex and more diverse objects.

In this episode, Toby's emotional reactions would alternate with his intellectual reactions. First he felt interested in spilling the purple smoke; next he transformed this interest by combining it with his interest in pouring liquids; then he felt interested in a new action, that of pouring the purple smoke into a beaker; then again he transformed this second interest. The existence of this dialectic between thinking and feeling provides *prima facie* evidence for an earlier claim. It suggests that learning may well result from the interaction between intelligence or knowledge on the one hand and emotion on the other.

In this brief discussion, of necessity I have begged a number of questions. For example, I have failed to provide an operational definition of 'interest'. More fundamentally, I have not

explained how knowledge acquires any coherent organisation; from my account, one might erroneously imagine that a typical sequence of experiences has no more unity than a chain of random associations. I will deal with these issues in later chapters.

For the time being, I wish to make only the following point. New knowledge emerges as a small transformation of pre-existing knowledge. But since you can rarely know in advance where a small transformation will lead, you can rarely foresee what new knowledge you are going to gain.

1.3 Freud and Piaget

In order to study the interaction between knowledge and emotions, one should first know exactly what knowledge is and what emotions are. Unfortunately there is no generally accepted definition for either of these concepts. Both knowledge and emotions have been investigated by scientists from many different points of view. As a result, we have many ideas about knowledge and emotions, but these ideas have not been synthesised into a unified theory. Thus I cannot rely on only one authoritative source from which to draw my conception of either knowledge or emotions; rather I must borrow ideas wherever I can find them.

But having adopted an eclectic outlook, I discovered that certain authors offer an especially rich collection of ideas. More and more I found myself relying on Piaget's views of knowledge and Freud's views of emotions. I cannot overlook the effect of my own pre-existing biases and knowledge on my acceptance of Piagetian and Freudian concepts; nevertheless I think there are objective reasons why one should expect a psychologist to find Piaget and Freud especially useful. Not only have they both produced a great many ideas, but more significantly, the recent history of Psychology has proven the usefulness of their ideas. No cognitive psychologist is currently more influential in the world than Piaget; no personality psychologist has exceeded the stature of Freud. It would therefore be surprising if Piaget and Freud did not prove useful in a study of both knowledge and emotions.

A common feature of both Piaget and Freud's research was the attempted creation of large unified theories. Piaget wanted to achieve a complete explanation of the development of knowledge; Freud tried to describe the general structure of the human mind. The comprehensiveness of their visions has often influenced the reception of their research by the scientific community. Psychologists have often neglected to evaluate each empirical study and theoretical analysis on its own individual merits. Rather they have tried to judge Piaget's and Freud's systems as wholes. Thus many psychologists have defined their attitudes to Piaget and Freud in global terms, as either Piagetian or anti-Piagetian, Freudian or anti-Freudian.

In the present study, I did not start intending either to vindicate or undermine any particular theoretical outlook. Rather than beginning from theory, my analysis started from data. Over a period of months, I collected weekly audio-recordings of three children in the process of learning. From these weekly sessions, I tried to determine exactly what the children were learning and what experiences contributed to their education. My main use of Piagetian and Freudian theory was as a source of analytic concepts. Before I could infer *how* my subjects were learning, I first had to discover exactly *what* they were thinking, feeling and learning. I adopted Piagetian and Freudian concepts whenever they helped to make these discoveries.

In later chapters, I will describe the specific facts which Piagetian and Freudian concepts were used to analyse. For the present, I will give examples of a Piagetian idea and a Freudian idea which often proved useful.

In a study of children's learning, it is necessary that one can recognise when a children's knowledge has changed. To help identify such a change, Piaget's research is extremely useful. For most of his career, Piaget's main interest was in describing the stages of intellectual development. The success of his research depended on his ability to distinguish children who had undergone some major intellectual change from others who had not. In study after study, Piaget used the same basic criterion to make this distinction. I will consider one of his more famous experiments to illustrate his

method.

In this experiment, Piaget (Piaget and Szeminska, 1941) would present a child with six eggs and six eggcups. The eggs and eggcups were both arranged in parallel straight lines so that each egg was opposite one eggcup. First Piaget would ask if there were more eggs, more eggcups or just as many of each. After the child answered that there were just as many of each (as all children did), Piaget would spread out the six eggs so that the distance between them became greater. Then he asked again if there were more eggs, more eggcups or just as many of each.

The younger children thought that now there were more eggs. When Piaget asked how they knew there were more eggs, they usually answered that the eggs went farther. On the other hand, the older children realised that there were still just as many eggs as eggcups. They often justified their answer saying "the eggs go farther but there's more space between them."

In this experiment as in most of Piaget's experiments, the difference between the older and younger children is that the older children take into consideration different properties of their environment than do the younger children. Usually the older children notice quantitatively more and/or qualitatively subtler properties. But for my purposes, it is the difference and not the improvement which matters. For the fact that they notice different properties is sufficient to prove that their knowledge of their environment has changed.

Throughout my study, I inferred that children's knowledge had changed when they began consistently to notice a property in their environment which they had previously ignored.

Just as Piaget provides a criterion of intellectual change, Freud provides a criterion of emotional change. It was often necessary for me to recognise when my subjects' feelings about the research were becoming more intense. The process of emotional involvement is an important theme in both psychoanalytic theory and Freudian psychotherapy. The concepts of 'cathexis' and 'transference' both refer to this process.

Transference occurs when a patient becomes emotionally attached to his or her

psychotherapist. Feelings previously reserved for a loved person, a parent or lover, become transferred to the therapist. Then the patient begins to act as if he or she were in love. The most obvious symptom is that patients will explicitly confess their love. They may also like spending time with the therapist. When physical interaction is impossible, they may interact symbolically with the therapist, in their thoughts. They begin to notice the therapist's attractive qualities, and they praise these. Psychoanalysts believe that transference is essential if their therapy is to work (Freud, 1958).

In the present study, I witnessed at some time each of these symptoms of transference. Since 'transference' has proven among the most useful of Freudian concepts in psychotherapy, I feel justified in interpreting these symptoms as Freud would have. All of these actions I see as signs of emotional attachment.

1.4 The Case Study Method

By adopting a small sample methodology, I further am following in the tradition of Freud and Piaget. Many psychologists prefer a 'broad but shallow' method in which they collect a small amount of data about a large number of subjects. In contrast, Freud and Piaget both use a 'deep but narrow' method in which they collect a large amount of data about a small number of subjects. The same factors which influenced Freud and Piaget have also led me to adopt the case study method.

Piaget's infancy study (1935, 1937, 1945) is a good example for illustrating the justification for the case study method. Stated briefly, Piaget's goal in this study was to trace the changes in infant intelligence from birth to 18 months. Before undertaking this study, Piaget could not have known the circumstances when infants display their knowledge. Indeed a task of the research was to discover these circumstances. In order to make such discoveries, Piaget required a large corpus of observations.

For a similar reason, my own study required a large number of observations. My goal was to identify the intellectual and emotional experiences which contribute to children's learning. But I

could not have anticipated when these experiences would take place. By collecting many observations, I increased the probability that I would witness these important experiences.

A requirement in Piaget's study was also that he discover the chronological order of many acts. This discovery would obviously have been difficult without observing all of these acts performed by the same child. A requirement in my study was that I relate many emotional and intellectual experiences to long term changes in a child's knowledge. This second requirement dictated also that I conduct a case study.

The main disadvantage of the case study method is its labouriousness. It takes weeks and months to isolate the significant events within a large body of observations; then the researcher must start to discover how these events relate to one another. Although one may wish to replicate one's results with a large sample, the task would be overwhelming. As in Piaget's study, I have had to be satisfied working with only three children.

1.5 The Clinical Method

Both Freud's and Piaget's research methods may be described as 'clinical'. Freud's studies were clinical in the generic sense of the word. Freud's discoveries resulted from observations made primarily for therapeutic reasons in the course of clinical treatment. Piaget broadened the term 'clinical' to include investigations which shared no therapeutic intent. He called his method 'clinical' because he treated his subject in the same way as a diagnostician would treat a patient. On the basis of his initial observations, he would develop hypotheses. Then on the basis of these hypotheses, he would collect further observations which could lead him to revise his opinions. He would continue this dialectic between hypothesis and observation until all the evidence pointed toward a specific diagnosis.

Piaget's method involves observing both words and physical actions. Freud relied heavily on verbal interviews rather than actions; nevertheless, this preference for verbal exchanges should not

be seen as an essential feature of his method. Other psychoanalysts have adopted non-verbal methods when they appeared useful.

The main dimension for distinguishing between Freud's method and Piaget's is that of directiveness. Piagetian research is typically highly directive. The researcher is constantly setting tasks in response to his current hypothesis. The subject is expected to perform the assigned tasks, answer all questions and do nothing more. In contrast, Freud's method is much less directive. The most popular psychoanalytic procedure is free association in which patients are expected to say everything that comes into their mind.

My study employed an eclectic clinical method borrowing from both Freud and Piaget. Like Piaget, I collected observations of both utterances and actions. At times I set my subjects specific tasks or asked them highly directive questions. Most of the time however, I was less directive. I created settings for my subjects in which they could invent things to do and subjects for conversation with relative ease. On one occasion, I asked a subject to free-associate. As the study progressed, I found that my method was becoming increasingly non-directive.

2. Micro-worlds and Conceptual Worlds

Most people would agree that children learn more than math in a math class. They learn communicative skills for expressing and understanding mathematical ideas. They learn motor skills for writing mathematical symbols on paper and on a blackboard. They learn social skills for interacting with both the teacher and other children. They also learn a number of specific facts about the setting itself. Children learn about the geography of the math classroom and about the personality of the teacher. So 'Math class' becomes a holistic experience with the mathematics itself being only one component.

But after the children leave the math class, the mathematics is supposed to acquire a life of its own. The children are supposed to retain a core set of mathematical facts which can be applied in all settings whether or not they resemble the classroom where the mathematics was learned.

Over the past few years, I have come to see much of our most important knowledge as specific rather than universal. I used to accept that the most interesting knowledge could be formulated either as concept types or in universal propositions. This knowledge was represented by such concepts as number, logic, matter and motion, by the theorems of mathematics and by the laws of physics. I also accepted Piaget's belief that universal knowledge should be studied by Developmental Psychologists; I thought that children's mathematical and scientific theories differed in content from those of adults, but were formulated in equally universal terms. Over the last five years, I have found myself forced to reject those assumptions. I presently see the idea of universality as a major intellectual achievement attained by only a minority of adults. Most knowledge, I think, is restricted to special contexts. Only with difficulty can we transfer knowledge from school to the playground, from home to work, from friends to family. Thus what school children learn is not really mathematics as a discipline but math class. Expressed in more general terms, *the object of learning is*

not subjects but settings. These special settings where knowledge is collected have been called *micro-worlds.*

The term "micro-world" refers to a fundamental unit of experience and like other fundamental concepts in Psychology (or indeed any other science), it has no rigorous definition. No more than Cognitive Psychologists can define the term "concept" or Personality Psychologists can explain the word "feeling" is it possible here to list the necessary features of a micro-world. Like these other basic concepts, the idea of a micro-world must be understood by watching it in action. By describing the micro-worlds of the past, I hope to create an image of what micro-worlds are and of why they are important.

My adoption of a "micro-world" theory of knowledge has been accompanied by a change in my intellectual loyalties. Five years ago, I was a student in Piaget's Department at the University of Geneva. Subsequently, I have become more and more interested in the theoretical point of view developed at MIT's Artificial Intelligence Laboratory (Minsky and Papert, 1974; Minsky, 1975; Papert, 1980; Minsky and Papert, In preparation) and in the psychological, educational and artificial intelligence research it has inspired. The more I have studied the MIT conception of knowledge, the more persuaded I have become of both the soundness and the importance of the micro-world concept for an understanding of learning and knowledge.

During the late 1960's and early 1970's, the special characteristic of MIT research was its concern with limited micro-worlds. Early in its history, Artificial Intelligence researchers had learned that computers have different predilections from people. On the one hand, computers could be programmed with relative ease to perform complex calculations that proved difficult for human beings; on the other hand, it was difficult to make computers reason according to common sense. Such "elementary" tasks as conversation, visual recognition and debugging motor skills, although well within the capacity of three-year old children, were too hard for the early computer programs.

The first successful implementations of common sense reasoning accompanied the

development of the micro-world concept. It was possible for computers to draw common sense inferences but only within highly restrictive contexts. The centerpiece of the most intensively studied micro-world was a set of children's blocks. In 1968, Guzman designed a system which could visually distinguish one block from another. Later Winston's (1975) program learned the concept of "arch" from seeing a horizontal block supported by two pillars; Sussman's (1973) program debugged its own inefficient procedures for stacking blocks; and Winograd's (1972) program could conduct conversations about blocks.

In their *1972 Progress Report*, Minsky and Papert (1974) used the term "micro-world" for the first time in print, while discussing intellectual domains like the blocks world. At the time, they considered the importance of micro-worlds to be practical rather than theoretical.

From Piaget, Minsky and Papert borrowed an epistemological view of intelligence. Like Piaget, they saw intelligence as a mechanism of adaptation; in the long term, the more you know about your environment and yourself, the better you are able to cope with fresh challenges. Furthermore they agreed that the physical laws of the world dictated in part what knowledge structures would prove adaptive. For a being to become highly intelligent, it would require these knowledge structures, whether it be an alien from outer space, a man-made robot or a human being. Minsky and Papert saw one goal of Artificial Intelligence research as the description of these general epistemological laws. Machines would become truly intelligent only if we discovered the knowledge required for real intelligence. By describing the knowledge for machine intelligence, we must also be discovering the knowledge underlying human intelligence.

Although Minsky and Papert accepted Piaget's thesis that epistemological laws must in principle exist, they rejected the specific epistemological theories which Piaget advanced. Piaget tried to describe the organisation of knowledge in terms of such general algebraic structures as groups and *groupements* (Piaget, 1947, 1970, 1974; Piaget and Inhelder, 1959; Inhelder and Piaget, 1956). But when Artificial Intelligence researchers began designing adaptively intelligent machines, they found

no function for Piaget's algebraic cognitive structures. Such structures seemed in no way to promote intelligent adaptation.

This last critique of Piaget underscores one contribution of Artificial Intelligence to Psychology. Because they need to make their programs work, Artificial Intelligence researchers become especially sensitive to the intellectual demands imposed by real micro-worlds. They tend to favour structures which serve a definite function and reject those which do not. A consequence of this radically functional perspective has been their willingness to postulate local micro-world-specific knowledge. Traditionally, most psychologists and epistemologists have been interested, like Piaget, in context-free properties of intelligence. They have sought general principles of perception, learning, memory and motivation which operate in all contexts. In their pursuit of universality, they have ignored the possibility that psychological functions are performed differently in different micro-worlds. The significance of much recent research in Artificial Intelligence has been its attention to micro-world-specific knowledge. It is now possible to see intelligence, not as a vast general-purpose structure, but rather as a society of special purpose structures, each one adapted to a particular micro-world.

The micro-world perspective leads us to ask new theoretical questions. One important question concerns the genetic inheritance of micro-worlds. The most fundamental lesson of Ethology has been that animals are innately adapted to their niche. From birth, animals display behaviour patterns which tend to facilitate adaptation in their natural habitat. It seems reasonable that human beings are adapted to our natural micro-worlds just as other animals are adapted to their niche. A task for researchers is to identify the micro-worlds which typically appear in all natural human habitats.

A second issue concerns learning. Clearly human beings function in settings to which they could not have been innately adapted. An important developmental process must therefore be the construction of knowledge about unfamiliar micro-worlds. I will use the term *conceptual world* to

refer to the mental representation of a micro-world.

I finally became persuaded of the micro-world perspective because of a study by Robert Lawler. Lawler (1980a, 1980b, 1980c, Reference Note 1) devoted a six-month period to an intensive observation of his daughter, Miriam, beginning at her sixth birthday. During that time, he observed virtually everything she did all day ever day; in fact, his only break from the research came after Miriam had gone to sleep. The documentation of his study included 91 recorded protocols between 30 and 60 minutes long (many of which were video-taped) and 130 vignettes typically three to four pages long, describing Miriam's behaviour outside of the recorded sessions.

Lawler saw his research as an investigation of natural learning. He wanted to discover from naturalistic observation how everyday experiences cause children's knowledge to grow. Since he did not try to teach Miriam any set curriculum, the content of his observation necessarily depended on what Miriam herself chose to learn. As one would expect, Miriam was interested in learning about many different domains; these included jokes, tic-tac-toe, computer programming and addition. Furthermore her learning about each of these domains was so extensive that Lawler had trouble describing her accomplishments even in 600 pages of text. For the purpose of the present discussion, I will limit myself to one tiny thread running through the dense fabric of Miriam's learning. I will describe how she discovered the principle of carrying in addition (Lawler, 1980c).

Consider the three micro-worlds where Miriam initially performed mental calculations. The first micro-world may be called the 'fingers' world. The fingers world was useful in addition because fingers can be placed in a one-to-one correspondence with numbers. When Miriam wanted to add 17 plus 6, she said, "Well seventeen" and then proceeded to finger-count "eighteen, nineteen, twenty, twenty-one, twenty-two, twenty-three. Twenty-three is the answer." On occasions, she generalised this counting procedure from fingers to hash marks.

The main constraint on the fingers world is its limitation to sums where one addend is less than or equal to 10. It could not calculate the sum of 15 plus 15 because there are not enough fingers.

A second micro-world may be called the 'coins world'. There were certain sums which Miriam could calculate but only when they were formulated in monetary terms. When she could not deduce that 15 plus 15 equals 30, she knew quite well that 15 cents plus 15 cents equals 30 cents. The basis of her deduction was the knowledge that two packs of gum (at 15 cents each) could be purchased for 30 cents.

Miriam's third calculation environment was the world of turtle geometry. This world was designed by Seymour Papert and his colleagues (Papert, 1971, 1972, 1980; Papert and Solomon, 1972; Solomon, In preparation) to embody high level mathematical ideas in a form which children can use. The first turtles were cybernetic animals covered by a transparent plastic shell, who traveled on wheels and wrote with a pen in the middle of their underbelly. These mechanical turtles were followed quickly by graphics turtles which live on a television screen and resemble triangles. Children control the motion of the turtle by entering commands into a computer terminal and by writing programs in Papert's LOGO programming language. According to Papert, the turtle world is a "mathland" where children become fluent in mathematics with the same ease as they normally learn to speak their native language (Papert, 1980).

A typical problem for Miriam might arise when she was trying to alter the direction of a turtle's motion. Once after turning the turtle 55 degrees to the right, she decided that she wanted to continue 22 degrees further. But before executing the turn, she wanted to know how much was 55 plus 22. The troubling feature of turtle geometry for Miriam was its extensive use of two-digit numbers. With numbers this large, Miriam could not rely on finger counting for a solution.

To adapt to turtle geometry, Miriam discovered a collection of well-known sums. One such sum is that 90 plus 90 equals 180. (Ninety is an important number in turtle geometry because a right angle is 90 degrees.) Another well-known sum is that 5 plus 2 equals 7. Although she discovered some sums by experimenting with the computer, she learned most by asking people for help.

Miriam learned procedures for adding and stripping zeroes. Thus she could deduce from

the fact that 5 plus 2 equals 7 that 50 plus 20 equals 70. She was also able to concatenate decadal and unit sums. Since 50 plus 20 equals 70 and 5 plus 2 equals 7, Miriam could infer that 55 plus 22 equals 77. But Miriam suffered from one great limitation; she could not compute sums which required carrying. So when she tried to add 55 plus 26, she arrived at the answer 76 (by adding 50 plus 20, concatenating 6 and forgetting the 5).

Just as Miriam had generalised her fingers world knowledge to hash marks, she also generalised her turtle geometry knowledge to straight mental arithmetic problems. But her calculations betrayed their ancestry in her handling of sums which required carrying. She continued to compute the decadal sum, concatenate one of the unit's terms, and neglect the other. The most compelling evidence for the micro-world perspective, I think, comes from Lawler's analysis of Miriam's calculations. In the light of this study, Piaget's theory of cognitive organisation is no longer tenable. As Lawler argues, Miriam could not have been acquiring a unified system of general arithmetic principles. The most reasonable conclusion is that Miriam was developing three independent conceptual worlds, each corresponding to one micro-world of her experience. For the sophisticated observer, there appeared a basic similarity among these conceptual worlds because they all included some knowledge of calculation. But for Miriam, this resemblance was too subtle. Within her mind, these three conceptual worlds co-existed in total isolation from each other.

For the sake of argument, let us consider two hypotheses about the content of Miriam's learning. The first hypothesis is that she was learning a set of related general principles, all concerning addition. According to this hypothesis, the particular setting did not affect the organisation of her knowledge. All knowledge about the same subject, addition, was represented together in her mind.

The second is the conceptual world hypothesis. It asserts that Miriam was learning not a set of general principles but rather a collection of unique experiences. It asserts that Miriam possessed not one unified body of addition knowledge, but rather three distinct bodies of knowledge, one

conceptual world for each of the three micro-worlds.

The two hypotheses can be compared because they would lead one to predict different behaviour. According to the general rule hypothesis, the current setting should not affect the knowledge that Miriam would invoke. Whether she is adding fingers or coins or angles, knowledge from the fingers world, coins world and turtle geometry world should all be equally accessible. The only reason to select one rather than another is because of its greater utility. But according to the conceptual world hypothesis, the current setting should be crucial in determining what knowledge Miriam would invoke. Since each conceptual world is represented independently of the others, one should expect that the current setting would activate the knowledge stored in its corresponding conceptual world.

Sums such as 55 plus 26 provide the data we need to compare the two hypotheses. As you recall, Miriam began this sum by adding 50 plus 20, concatenating the 6 and producing the result 76. At this point, Miriam's knowledge of finger counting would have proven extremely useful. By creating a one-to-one correspondence between her fingers and the remaining 5 she could have said "seventy-six (and then counting on her fingers) seventy-seven, seventy-eight, seventy-nine, eighty, eighty-one" thus finding the correct answer.

The general rule hypothesis would predict that she would indeed invoke this useful counting principle. On the other hand, the conceptual world hypothesis would predict that she had distinct conceptual worlds, one derived from the fingers micro-world and another from the turtle geometry micro world; Lawler called these two conceptual worlds the 'count' world and the 'decadal' world. Since the sum in question had invoked only the decadal world, knowledge from the count world would be inaccessible.

In this instance, and in other similar ones, Miriam behaved as the conceptual world hypothesis would predict. Consistently, she used knowledge from one conceptual world in isolation from the other conceptual worlds.

Eventually Miriam did succeed in synthesising the decadal world with the count world. But Lawler found evidence of this synthesis only after he explicitly asked her to finger-count in a context where she would normally use decadal knowledge. Three and a half months after the beginning of the study, the following conversation took place.

"Miriam, do you remember when you used to count on your fingers all the time? How would you like to do a sum like seven plus two?"

"Nine."

"I know you know the answer--but can you tell me how you used to figure it out before you knew?"

(Counting on fingers) "Seven, eight, nine."

"Think back even further to long ago, to last year."

(Miriam counted to nine with both addends on her fingers--leaving the middle finger of her right hand depressed.) "But I don't do that anymore; why don't you give me a harder problem?"

"Thirty-seven plus twelve."

(With a shocked look on her face) "That's forty-nine!"

Lawler interpreted the shocked look as reflecting the sudden realisation that finger counting and decadal knowledge can be used to solve the same class of calculations, i.e. additions. During the following week, Miriam discovered the finger counting solution to the carrying problem.

According to Lawler, it was no coincidence that Miriam discovered the finger counting solution when she did. Previously, she had been unable to relate the Count World for finger counting to the Decadal World for turtle geometry because they had never both been activated together. But when Lawler provided a stimulus which simultaneously invoked both conceptual worlds, Miriam could begin to perceive their intimate connection. It therefore was not surprising when she constructed a new algorithm for addition out of components from different ancestral

conceptual worlds.

By watching all of Miriam's actions, Lawler was able to argue that experience imposes definite limits on how different items of knowledge may interact. The human mind is not so flexible that we can connect any two ideas whenever such a connection would prove useful. But rather the only ideas which connect easily are ones which belong to the same conceptual world. Knowledge from distinct conceptual worlds can sometimes interact; but these interactions represent unique and important intellectual experiences.

My commitment to the micro-world perspective played a central role in the design of the present study. Lawler had shown convincingly that children organise their knowledge into conceptual worlds but he had not explained how such a complex intellectual structure can be constructed out of a series of individual experiences. In contrast to Lawler's emphasis on the organisation of knowledge, I wanted to investigate the process of learning. I wanted to observe children interacting with a defined micro-world to detect how their experiences caused their knowledge to grow.

My study included three subjects: Leonardo (age 8), Toby (age 10) and Jonathan (age 13). I made contact with each child through a different process. I met Leonardo through the Cambridge, Massachusetts elementary school where he is a student. Leonardo volunteered to serve as a subject after all the children and parents in his school were notified about the research. Toby is a student at an elementary school in the Boston suburb of Acton, Massachusetts. Toby's principal and teacher were both interested in this research and they felt Toby could afford to miss a few hours of class-time. I met Jonathan through a Saturday program at the Boston Museum of Science. The director of the program agreed to publicise my need for subjects and Jonathan responded to the publicity. The three children came from different economic classes. Leonardo's father is a skilled labourer and the other children's parents are professionals. To my regret, all three subjects were of the same sex.

I designed two micro-worlds in which to observe my subjects, the *Chemicals World* and the

Mork and Mindy World. When I began my study, the Chemicals World was organised around a collection of household chemicals: sugar, salt, bleach, sand, honey, flour, paper, soap, string, steel paper clips, copper wire, aluminum foil, wood and tap water. I also provided the apparatus for heating chemicals (bunsen burner, tripod, a clamp, safety goggles) and for mixing them (beakers of various sizes, spoons, a funnel and an infinite supply of test tubes). But during the first session, Leonardo asked, "You think you could get chemicals that people use for making experiments in laboratories?" For later sessions, I also included a supply of laboratory chemicals. A list of these chemicals is provided in Appendix 1.

The *Mork and Mindy* World developed from an informal survey of elementary school children. When I asked a number of children (about 15) to name their favourite television series, the consensus chose *Mork and Mindy.* So *Mork and Mindy* became the focal object of my second micro-world.

Each research session ran approximately for one hour. In the Chemicals World, the children spent 55 minutes conducting experiments; during the last 5 minutes, we cleaned up. In the *Mork and Mindy* World, the first 25 minutes was spent watching the program, and the rest of the session was spent in discussion.

My original plan was to see each child for six weekly sessions in both micro-worlds. During the research, however, good reasons arose for modifying that plan. The only child to stay less than twelve weeks was Leonardo who chose to withdraw before completing his last two sessions in the *Mork and Mindy* World. The other two subjects worked for more than the expected twelve weeks. Toby spent eight weeks in the Chemicals World; Jonathan worked there for eleven weeks. Both Toby and Jonathan spent the expected six sessions watching the *Mork and Mindy* tapes, but Jonathan devoted an additional seventh session to discussing his overall impressions of the television series.

The research sessions included both interviewing and non-obtrusive observation. As I noted in the opening chapter, my interviews combined the clinical methods of Freud and Piaget.

3. Jonathan

In this chapter, I will describe the experiences of a thirteen year old boy in the *Mork and Mindy* World. During the study, I witnessed definite changes in Jonathan's knowledge and feelings about the television series in particular and about fiction in general. My goal is to document Jonathan's behavior and to advance a partial explanation of why it changed. I will argue that the development of Jonathan's knowledge and the intensification of his feelings were related phenomena. I believe that the constant interplay between his thinking and feeling was the ultimate cause of Jonathan's learning.

From the time when he entered the *Mork and Mindy* World, Jonathan was interested by the television program's humour. During the first week, we had spent considerable time discussing various jokes in the episode. Then early in the second session, I asked him if he considered this week's program funny too.

"Ya," he answered, "they're usually funny."

"What was funny about it?"

"This wasn't really that tied in but again his imitations, when he tried to talk the guy into being a believer in the Friends of Venus. That whole idea that somebody was going to come down on Labour Day. His imitation of the telephone. And I think the basketball thing was especially funny."

"What made that especially funny?"

"Just the idea that it's different. He sees things different from humans."

"What's the difference between the way Mork would see things and the way people would?"

"Mork learns from what he sees but sometimes he doesn't get the right idea about things. When they stand up and play music you might think you're supposed to dance."

"Let's say a Chinese was visiting America, that's what they'd think?

"No 'cause if everybody is standing like this and nobody's moving, I think you'd get the idea. If... I don't know."

"If you're an Orkin, you might think they're dancing?"

"Ya."

That week, I had shown Jonathan an episode in which Mindy had sent Mork to a basketball game so that she could spend the evening alone with a boyfriend. While Mindy and her friend were embracing, Mork arrived unexpectedly at the door. Confronted with this undesired presence, Mindy demanded, "Oh Mork, what did you do?"

"Lots of things. I had a great time. Ever been to a basketball game? My favourite part was when I got to dance."

Mindy's friend was dumbfounded. "You danced!"

"Oh ya that part at the beginning when everybody stood up and they played the music: 'Oh say can you see'."

Jonathan first mentioned the basketball joke within the context of a discussion about humour. He used the incident as an example of a particularly funny joke. But soon a second issue began to capture his attention. He became interested not in the humour of the incident but in its realism.

His initial reaction was that the incident was realistic. "When they stand up and play music," he observed, "you might think you're supposed to dance." But within a few minutes, he started to have doubts.

After our first reference to the basketball joke, the discussion moved to a fresh topic. Jonathan began to analyse the difference between human beings and Mork. Then suddenly for no apparent reason, Jonathan changed his focus from the psychology of Mork's personality to the dramatic interpretation of Mork by the program's producers. "Sometimes it would be the way a person from another planet would act. Sometimes they exaggerate. Like sitting when he sits upside

down. That wasn't in this one, but they exaggerate a lot. They might not get the idea of sitting like they're supposed to do. They might sit in a weird way but they wouldn't actually sit upside down."

I could see no reason why Jonathan at this time should raise this issue. In no previous discussion had we ever talked about exaggeration. I asked him, "Why do you think they exaggerate?"

"To make it funny."

"Do you think it's funnier when they exaggerate than when they don't?"

"Ya."

"But you don't think they exaggerate all the time? Sometimes it's believable?"

"Sometimes it's almost believable, not really, really believable." Then he let me see how the issue of exaggeration related to our previous discussion. "Like at the stadium when he thought he was supposed to dance, it's sort of believable. You know, music and standing up. But I wouldn't think somebody would do that."

"Suppose you were directing the program. Would you worry about whether Mork was acting like a real person from outer space?"

"I would probably think about what a person would do and then add on to it. First he might see people dancing to music standing up. And then possibly he might think not to dance when he sees everybody serious. So possibly add not to stop. So I'd first think of the thing and then add on."

It appeared that Jonathan had begun to question his original interpretation of the basketball joke. At first he had considered the incident completely realistic. But on second thought, he began to doubt that Mork would dance when all the other spectators were standing so seriously. It was "not really, really believable" that a spaceman would dance to the *Star Spangled Banner*. He had raised the issue of exaggeration to explain why the producers would have Mork behave unrealistically. For Mork to dance at a basketball game is an exaggeration of his character. But such exaggeration is understandable in a comedy because it makes the program funnier.

We discussed the basketball joke again toward the end of the session. By this time, Jonathan was prepared to commit himself wholeheartedly to his revised interpretation of the incident. "I don't think he'd really do that moving his legs and everything when everyone's so serious. I think if you're learning like that, you'd probably follow what everyone is doing *exactly*. And not change a bit. They do it to make it funny."

Between the beginning and the end of this discussion, there was a definite change in Jonathan's opinion of the basketball joke. At the beginning of the session, he considered the joke realistic. He thought that "when they stand up and play the music, you might think you're supposed to dance." By the end of the discussion, he had changed his mind. He thought that the producers of the program had exaggerated Mork's behaviour for a comic effect. He thought that a real spaceman would "probably follow what everyone is doing exactly, and not change a bit."

This change of opinion reflected an increase in Jonathan's knowledge about the joke. At the beginning, the joke evoked a single association: when music makes people stand up, they often begin to dance. Subsequently he brought other facts to bear on his analysis of the joke. My question about the hypothetical Chinese visitor to America elicited some knowledge about how strangers act in a strange land. He observed that foreigners usually imitate the natives as exactly as possible. He inferred then that Mork would probably be just as solemn as the other spectators when they played the *Star Spangled Banner*. Jonathan also noted that Mork's behaviour is influenced by the intent of the production staff as well as by Mork's personality. On previous occasions they had exaggerated Mork's idiosyncrasies beyond the believable. For the basketball joke, it was plausible that they were engaging in more exaggeration.

Throughout the discussion, Jonathan's opinion became more sophisticated as an increasing number of considerations influenced his judgment. Thus Jonathan's analysis produced not only an intellectual change but also an intellectual advance. The more he thought about the basketball joke, the better he recognised the factors which influenced Mork's actions.

Jonathan's interest in the basketball joke appeared to deepen as he learned more about it. At first, his interest seemed quite casual. He mentioned the joke only because it exemplified the humour of *Mork and Mindy*. But later he became interested in the joke for its own sake. After he raised the issue of realism, Jonathan began to analyse the cause of Mork's bizarre behaviour. Eventually it was Mork's psychology and not his weirdness which held Jonathan's attention.

Initially Jonathan appeared quite content with his explanation of why Mork would dance. His first signs of doubt appeared after I asked if a Chinese visitor would also dance. He was sure a Chinese would not dance. But then he hesitated before reaffirming that a spaceman, like Mork, would dance.

Then spontaneously he mentioned reasons for doubting that Mork indeed would dance. The first of these reasons was the presence of exaggeration. Jonathan knew of other times when Mork had performed acts unexpected from a spaceman. The second was the issue of imitation. A spaceman, like a Chinese visitor, would copy other people, even when their actions seem surprising and illogical.

By the end of the session, Jonathan's feelings and opinions had both changed. He now appeared more confident in his own judgment; he no longer expressed doubt in his own opinion. But the opinion he now trusted was different from the one which he had earlier doubted. He no longer considered Mork's dancing realistic. It seemed that his doubts had forced him to change his mind and that this change in his opinion in turn had quieted his doubts.

Thus we may describe Jonathan's analysis of the basketball joke as an interplay between thoughts and feelings. His interest in humour made him notice the joke. Then this observation led to his interest in Mork's personality. This second interest inspired a number of explanations of Mork's behaviour. In the course of devising the later explanations, he began to doubt some of his initial impressions of Mork. Finally he resolved these doubts by concluding that Mork's behaviour at the basketball game had been exaggerated.

The basketball joke illustrates two processes which recurred often throughout the study. The first of these was the interplay between thinking and feeling. Regularly new ideas would evoke new feelings in Jonathan, and these new feelings would determine the subsequent direction of his thinking. The second was the process of changing his mind. As Jonathan discovered new facts, he continually revised his earlier judgments. Thus Jonathan's learning displayed the same developmental pattern as Piaget observed in his conservation experiments. Like Piaget's subjects, his ultimate judgments often directly contradicted his earlier ones. And furthermore, his reason for changing his mind appeared the same as the reason of Piaget's subjects: his discovery of new facts forced him to realise the superficiality of his initial opinions.

This chapter will relate the story of a complex learning experience. During his seven weeks in the *Mork and Mindy* World, Jonathan acquired not only a revised interpretation of individual episodes but more importantly a small but powerful set of new conceptual categories. Although one would expect concept learning to be a complex process, our awareness of its complexity makes the process no easier to describe. The same events elicited many reactions in Jonathan, some intellectual, others emotional. To discuss his most fertile experiences in depth would require such a continual alternation between cognitive and affective points of view that even the most attentive reader would become lost in the confusion. I have therefore chosen to tell three stories, one about Jonathan's ideas, a second about his feelings and a third about their interaction. Since all three deal essentially with the same material, I was unable to avoid a certain amount of redundancy. I felt however that redundancy was an acceptable price if that was the sum which clarity exacted.

According to Jonathan, his entire perception of *Mork and Mindy* changed as a result of our discussion. During the seventh session, Jonathan remarked: "Seeing the program like this and talking about it makes you see the program better. Like when I used to watch it and other TV programs like *Happy Days*, I'd just get the program, watch it and turn to the next program. Here when we watch *Mork and Mindy*, you get more to know the characters and to know what's going on.

So now when I watch *Mork and Mindy*, I see the characters as we've talked about them. Mork as getting more feelings as the weeks go by and. . . .Now when I watch *Mork and Mindy*, it's a lot different from when I watch another show during the week because I just see the show differently."

In this statement, Jonathan is claiming that he changed in two related ways. One change was perceptual. He says first that he "sees" the program better and later that he "sees" the characters as we have talked about them. A second change was cognitive. He says that he has gotten to "know" the characters more and to "know" what is going on.

Jonathan's own observations conform quite closely with mine. From week to week, I observed that Jonathan was accumulating knowledge about the various characters and that this knowledge was influencing his perception of the program. Let me describe how his perception of one of the characters changed. The character is the program's protagonist, Mork.

I began the first session by asking Jonathan a few preliminary questions about *Mork and Mindy*. In retrospect, these opening comments provide a useful clue about Jonathan's initial perception of Mork.

"The television program you will be seeing is *Mork and Mindy*. Have you seen it?"

"Ya."

"Do you like it?"

"Ya."

"Why do you like it?"

"It's funny."

"What makes it a good show?"

"The person's different. The idea that he's different makes it a good show."

"What kind of thing does he do differently?"

"Oh just drinking, and sitting on a chair. Everything from sitting on a chair to drinking he does differently. He does it different from us and that makes it funny."

"Give me an example."

"He does imitations very well, supposedly probably because he's from the other planet. Also drinking from his finger, sitting upside down."

These comments reveal quite a bit about the initial state of Jonathan's knowledge. It is obvious that he has seen the show a few times. He knows that the program focuses on a single character; he knows that this character is funny; and he can report some of this character's most distinctive acts. But he does not show any deep familiarity. Most strikingly, he refers to the protagonist, not by name as would be expected, but by the overly general expression "the person." This suggests that he did not even remember Mork's name.

But the main significance of this episode is that it reveals his initial opinion of Mork. For Jonathan, the most salient fact about Mork was his strangeness. As Jonathan said, the program is good because the person is different.

During the first week of the research, Mork's strangeness continued to be an important theme for Jonathan. During the second session, he commented twice that Mork was different from human beings. After that, Jonathan did not refer to Mork's weirdness.

Most of our discussion during the first session focused on particular incidents. On my suggestion, Jonathan rewound the video-tape to his favourite episodes. Then whenever he noticed anything especially interesting, he would stop the tape and comment on it. Most of the time, Jonathan chose to stop the tape after particular jokes so that he could explain why they were funny. A recurring theme in his explanations was Mork's weirdness.

One of Jonathan's favourite episodes involved a dinner party given by Mork. Much of the humour for Jonathan was in the weird foods that Mork served. I will quote Mork's words as he served his dishes, followed by Jonathan's commentaries.

(1) Mork: My salad is burning.

Jonathan: That is one of the funny foods I was saying. Salad
   burning. Get the idea? It's not normal.

(2) Mork: We will begin with a little malox au gratin.

   Jonathan: Another weird food, malox au gratin. Because malox is
      a medicine. You'd probably think he was weird
      It probably would mean there was medicine in the food
      which would make it taste terrible.

(3) Mork: I'm sorry; I forgot the soup forks.

   Jonathan: Another thing you know isn't normal, 'cause you
      can't use a fork to eat soup.

(4) Mork: Le peas frozanne.

   Jonathan: One of the weird foods. You see it this time.
      Frozen peas. That's not what most people eat.

Many weeks later, Jonathan recalled that he had originally perceived Mork as basically a very strange character. "Before I came here, I was thinking of *Mork and Mindy* as a fantasy science-fiction type of program. But now it seems, the more we talk about it, the more realistic it seems. Like this really happened. Mork becomes more of an earth person than a science-fiction man-from-Mars-sort of thing."

Jonathan's perception of Mork showed its first sign of changing toward the end of our discussion of Mork's dinner party. After being offered so many unpalatable dishes, Mork's guest, Mr. Bickley, became exasperated. He complained, "You two are doing this so I'll leave."

Then Mindy came to Mork's defense. "No, Mork is honestly trying to cook a good dinner."

Here is Jonathan's commentary. "He doesn't think that's true. But because he's different from the other planet, which I said makes the show funny, it really is true that he's trying to cook this meal good. He likes this guy; he thinks the guy's nice."

Jonathan is still *talking* about Mork as a spaceman. He says explicitly that Mork is different and that he is from another planet. But for the first time, he is *thinking* about Mork as if he were a human being. First he is attributing feelings to Mork; he says that Mork *likes* Mr. Bickley. But far

more importantly, he is seeking a psychological explanation for Mork's behaviour. He sees Mork's actions as resulting from his goals.

Psychological causation became for Jonathan the defining property of a realistic act. Jonathan was prepared to believe that Mork's knowledge and feelings might differ in some specifiable way from those of a human being. But he still expected Mork to act like a human being in fundamental ways. First he expected Mork to pursue the same kinds of goals as people pursue. Second he expected Mork to reason the same way as people do. When he found a discrepancy in either Mork's goals or his reasoning, Jonathan considered the resulting actions unrealistic.

After the first session, I had no reason to suspect that 'realism' would become an important theme in Jonathan's thinking. It would have seemed quite normal if Jonathan, like Toby and Leonardo, had subsequently neglected the psychological dimension of *Mork and Mindy*. However, Jonathan remained interested in Mork's psychology for the entire study. He returned again and again to the idea that fictional characters can have the same deep psychological make-up as human beings while differing from people in some superficial characteristics. We may call this idea 'fictional realism'.

It was during the second session that 'realism' became transformed from a simple idea into a subject for reflection. From the dinner party incident, Jonathan had learned that Mork's behaviour can be influenced by his psychology. So he expected the same degree of consistency between Mork's actions and his personality as one normally expects from a human being. But during the second program, he discovered that Mork is not as consistent as a real human being. For unlike a human being, Mork's behaviour is influenced not only by his personality but also by the dramatic goals of the program's producers.

You will recall Jonathan's initial reaction to the basketball joke. When he first heard the joke, he assumed that Mork's behaviour reflected his personality. Jonathan recognised that people do not normally dance at a basketball game. But as he explained, "Sometimes he doesn't get the right

idea about things. When they stand up and play the music, you might think that you're supposed to dance."

The essence of Jonathan's justification is that Mork, in his opinion, was reasoning in a human-like way from insufficient knowledge. But on further reflection, he eventually changed his mind. He no longer thought that Mork was reasoning in a human-like way. He felt rather that they were exaggerating Mork's character to make the program funny.

It was an important realisation for Jonathan that the program's producers could distort Mork's character. Without this discovery, he would have continued to assume that all of Mork's actions were realistic. Now however he could never be sure whether or not a given action was realistic. So 'realism' became a subject for reflection. Whenever he watched Mork, he could speculate about which actions were realistic and which ones were exaggerations.

The long-term significance of the basketball joke is that it provided Jonathan with a rich subject for thought. Again and again, he asked himself if Mork was behaving realistically. To answer this question, he was forced to think carefully about Mork's personality; only through such an analysis could he determine how one should expect Mork to react to any given circumstance. Having discovered this question of realism, Jonathan became captivated by it. By the end of the study, the concept of fictional realism had become a dominant theme in Jonathan's thinking.

This point can best be defended by examining the way fictional realism became proliferated through Jonathan's intellectual world. Before the study had ended, I was able to observe three stages of this proliferation. During the first stage, Jonathan's interest focused on the character of Mork. In a variety of situations, Jonathan tried to decide whether or not Mork was behaving realistically. During the second stage, Jonathan generalised the concept of realism from the character of Mork to the plots of the various episodes. During the third stage, he generalised it to other television series and to other fictional media.

We have already discussed two of the most important incidents from the first stage, those

being the dinner party incident and the basketball joke. During the following weeks of the study, Jonathan judged other of Mork's actions in terms of their realism.

After running away from Mindy, Mork came across a meeting house for a group called the 'Friends of Venus' and went inside. Jonathan commented: "I like the idea of the Friends of Venus and all that 'cause it's fairly realistic. I mean if someone from the other planet, if they saw this building is the Friends of Venus and he had been to Venus, he would go inside. He'd think these people are like him and he wants to meet people like him."

Jonathan obviously does not mean that one expects the Friends of Venus in downtown Boulder. But if a spaceman encountered this unlikely sight, he probably would go inside. Such a reaction is psychologically believable.

During the third episode, Mork found a pet caterpillar. But soon after Mork brought his pet home, it became immobile and Mork concluded it was dead. Jonathan thought that "this was the most realistic, more than the other times. It was all about a caterpillar changing into a butterfly. They didn't realise it was changing into a butterfly; they thought it was dead."

As in the basketball game, Jonathan considers that Mork reasoned in a human-like way from insufficient knowledge. Mork did not know that caterpillars metamorphose into butterflies, but he did know that immobility is a symptom of death. So although Mork's verdict is bizarre, Jonathan nevertheless finds it realistic because it may be the result of a human-like inference.

Early in the fourth episode, Mindy found her necklace missing at the end of a party. As an act of friendship, Mork telephoned all the guests at the party to know if, by any chance, they had stolen Mindy's necklace. Jonathan's initial reaction to this act was mild skepticism. "Calling them and asking them did they steal the necklace, it's a little unrealistic but it could be something he could do in that situation."

To open our discussion of the fifth episode, Jonathan offered his most subtle analysis to date of the issue of realism. "Well I noticed this time it was much more realistic about what a person

from another planet would do. First of all at the beginning in the marriage, it's possible that he might think that the person was trying to hurt the bride and groom by throwing rice, which might look like pebbles. The. . .I don't remember the other. . . the midget holding her back might look like. I don't know if it would look like that 'cause she's going so slow. That might be the way he sees it if he doesn't know. If he doesn't know why there is a midget, or a kid, holding the dress. You know you might get the feeling he's trying to hold her back. Actually that would depend on how smart the person from the other planet is. If he was smart, the person would figure out--I'm not saying Mork isn't smart or anything--in a realistic thing he would probably figure out that the dress is so long it has to be held up. You know if the person wasn't too smart, he might think. . . I don't know what it would look like."

Late in the third session, Jonathan first generalised the concept of realism to a character other than Mork. After Mork determined that his pet caterpillar had died, he arranges to hold a funeral. In the absence of a professional clergyman, Mork himself imitates the way a rabbi might conduct a funeral. Jonathan offers a commentary. "The whole scene's funny because that is what they say in some funerals. . . .This whole thing he does right now is a good imitation of what happens at a funeral. Sort of exaggerated a little bit. What they would say."

The difference between this and other commentaries is subtle but important. As in previous incidents, Jonathan is judging the verisimilitude of one of Mork's actions. But unlike the earlier times, he is not asking if the action is realistic for Mork, but rather if it is realistic for the person Mork has imitated. Jonathan does not consider whether it is psychologically plausible for Mork to imitate a rabbi; he asks only if it is psychologically plausible for a rabbi to mutter the phrases that Mork echoes. Rather than wondering if Robin Williams is giving a realistic portrayal of Mork, Jonathan now wonders whether Mork is giving a realistic portrayal of a rabbi.

During the fourth session, Jonathan judged the plausibility of an action by a supporting character, Mr. Bickley. We learn eventually that Mindy's neighbour, Mr. Bickley, had been the one

to steal her necklace. We are also told that he stole the necklace as a ploy to attract Mindy and Mork's attention. Jonathan considered that "it wasn't as thought out as the last one. Well it didn't really make as much sense. To take things 'cause he's lonely to get them to go down there, that doesn't make too much sense. That's not very realistic."

Jonathan later added, "I think for one thing, if this was a real situation, he wouldn't do something like that. He would, at least in my opinion, *I* wouldn't do something like that. I would do other things I could do. Call them and tell them to come downstairs 'cause their dog is. . .I think it's better to tell a lie over the phone or to walk up to their apartment and say, 'I need your help lifting my couch; I'm not strong enough' than to steal stuff. For one thing, they could have called the police not knowing it was him."

The main incident from the fifth episode was that two children decided to marry with Mork conducting the wedding ceremony. In discussing this social interaction, Jonathan observed, "Actually, I think this is the most realistic of them all. This one, not real life realistic but show realistic. Without Mork, this wouldn't happen, because I don't believe that anyone from earth would do what Mork did. You know, marrying them and stuff. But this is the most realistic for the show. For the characters of the show and the way the show goes, this is the most realistic."

Jonathan proceeded to make quantitative assessment of how realistic were various episodes. The wedding, he gave a rating of 90%. The opening episode, he gave a rating of 25%. He thought that the theft story could have happened also 25% of the time. As for the caterpillar story, contrary to his earlier opinion, he now thought

that was pretty unrealistic. He did not think it would happen.

Jonathan also made an overall assessment of the sixth and final episode. "This one, the idea, the general idea was okay but the idea that the cabin fell apart, that wasn't too realistic. The idea that what might happen if they got trapped in the woods: the fire might go out and you know, that whole idea of the cabin falling apart when Mork kicks it, that wasn't too realistic. The general

idea wasn't too good; it wasn't too realistic."

We thus see a progression. At first, Jonathan judged the realism only of individual acts of an individual character, Mork. Later he rated the realism of entire episodes. Beginning in the seventh session, he entered a third stage where the television series became his unit of analysis.

During the seventh session, he explained that realism had become an important theme in his experience of many television series. "I was thinking about this during the week; not only on *Mork and Mindy* but with other shows that I like a lot and get involved with and stuff. I try not to but I have to think how these are just actors playing parts in these stories. I don't like to think about it. I'd think especially in *Mork and Mindy* that they act it out so good that you wouldn't even think about it. I don't think I've ever mentioned, except in the case of Robin Williams, that these are characters playing the parts. It's hard to think of it that way in any TV show or movie where they are very good actors."

Jonathan went on to describe a television series where he felt that high quality acting made the characters appear realistic. "There used to be a show called *What's Happening*. It was about three boys; they start out at 15 or 16 and you see them sort of get older as one goes to college, two go to college. . . .When he went to college, they made him smarter, which would probably be harder to do especially for the actor. He was used to acting his normal way for a year and now they tell him, 'Now you're going to college; you have to act smarter.' If someone told me, 'Jonathan, you have to act smarter,' I don't know. It would be hard to do. Unless until then he had been acting dumber than he is, but I doubt it. If someone said, 'Act out the role,' you act out the role. But if someone said, 'You have to act smarter or act dumber or act more serious,' it would be hard to do."

From time to time Jonathan told me about movies and television programs he had been thinking about in terms of their realism. One week he mentioned a movie he had just seen. "It wasn't too factual. It was about this angel who supposedly came to help this guy along and he'd disappear and appear and it wasn't no way. . . I only saw the first half hour of it and it wasn't very

good."

Another week, I asked if he knew of any shows that are realistic in the same way as *Mork and Mindy*. He answered, "I was thinking about one. Well something like *Battlestar Galactica* where it's science fiction. Where they can go over and pull a spaceship toward them using a tractor beam, and blow it up using a supersonic laser and get out of there going 5 million lightyears, I don't know. It doesn't sound realistic but it is realistic to the show. It's realistic on *Battlestar Galactica* where they can blow up another spaceship using a laser."

By the end of the study, Jonathan was applying the concept of realism to a large class of objects. This class was not unbounded. Jonathan never thought to analyse the realism of paintings or sculptures, although the concept applies equally to the visual arts and to the verbal. Nevertheless Jonathan's class of potentially realistic objects was far broader near the end of the study than near the beginning. During the second and third weeks, Jonathan judged the realism only of individual incidents; by the ninth week, he could assess whether an entire television series was realistic. By the end of the research, Jonathan was applying the concept of realism to every component of a dramatic work.

The proliferation of this concept was not the result of one single insight. On the contrary, it was caused by a series of small insights; each insight showed Jonathan that he could apply the concept of realism to a slightly larger class of objects. At first he limited it to individual events involving Mork; second he included the actions of characters other than Mork; third he evaluated entire episodes; fourth he considered complete television series; finally, he generalised the concept to other fictional media. Thus through a series of small steps, Jonathan's class of potentially realistic objects became larger and larger.

At times, Jonathan spent two or three sessions without expanding his class of realistic objects. Between the second and fourth weeks, Jonathan concentrated on the actions of Mork. He kept finding new incidents where he could judge whether Mork was behaving realistically. During

this time, Jonathan generalised the concept of realism within a class and not between classes. He was finding new elements of the class of 'Mork-actions' whose realism could be assessed.

When Jonathan generalised his concept between classes, his new enlarged class was only slightly more general than his previous restricted class. He did not generalise immediately from the class of Mork-actions to the class of all dramatic-actions. Rather he moved from the sub-class of Mork-actions to the slightly larger super-class including all actions from *Mork and Mindy*. Next he moved to an even larger super-class involving not only incidents but also episodes from *Mork and Mindy*. Then he advanced to a third larger super-class which included television series as well as episodes and incidents. Thus although Jonathan kept extending the concept of realism to a larger class of objects, he expanded this class as gradually as he could. He seemed to move from a sub-class to the nearest conceivable super-class. In Piaget's vocabulary, we would say that the concept of realism generalised *'de proche en proche'* (literally 'from near to near').

Jonathan was rarely able to decide quickly or mechanically if an event was realistic. The decision often required considerable reflection. As part of this reflection, Jonathan was often led to notice phenomena which he had previously overlooked. These observations, made originally to settle the question of realism, could provide the seeds for the growth of new concepts.

We have already discussed one such instance of fertilisation. Although Jonathan originally considered the basketball joke realistic, he later changed his mind. His final verdict was that instead of being realistic, the joke was an *exaggeration*. Throughout the rest of the study, the concept of exaggeration acquired a modest yet real importance. When Jonathan considered an incident unrealistic, a standard criticism was that the incident had been exaggerated. You will recall how Jonathan evaluated Mork's imitation of a rabbi. "This whole thing he does right now is a good imitation of what happens at a funeral. Sort of exaggerated a bit."

Nevertheless the concept of exaggeration was not especially important to Jonathan. He mentioned it occasionally but not often. However the same cannot be said about another concept

born through the same process.

You will recall that the fourth episode concerned the theft of Mindy's necklace. You will recall also that Mork telephoned the members of Mindy's high school graduating class to ask if they had stolen the necklace.

Jonathan first mentioned Mork's telephone calls as an example of a good joke. "My two favourite jokes in this were when he was trying to use the melon as a ball and where he called the whole high school class. Both fit under the category like they're things he could possibly do. For all he knows, a melon might look like a ball he could bounce up and down. Calling them and asking them did they steal the necklace, it's a little unrealistic but it could be something he could do in that situation."

We talked a little about the melon joke. Then I returned to Mork's telephone calls. "The other joke you thought was good was him calling her high school graduating class."

"Ya but that's not as realistic."

"In what way was it unrealistic?"

"The call itself. When he said, 'Did you steal the necklace', I think he would know if it was a real person that you wouldn't call somebody and ask them that sort of thing. Though they do say he doesn't have any emotions. Maybe on his planet somebody would say 'yes'. Maybe they don't have madness and stuff like that."

Shortly after, Jonathan explained the connection between on the one hand feeling emotions and on the other, accusing random people of theft. "You don't want to hurt somebody's feelings by saying that. By saying that, you are making them think you don't trust them."

Jonathan seemed to have found an explanation for an act which at first seemed unrealistic. People normally avoid such accusations because they do not want to hurt someone's feelings. Since spacemen lacking feelings could not understand such a taboo, it is not surprising if they do not respect it. Mork's action would therefore seem realistic if you accept that he feels no emotions.

Thus Jonathan had transformed the question of realism into a question of emotion. He no longer was seeking direct evidence for and against the realism of Mork's act. Rather he was trying to determine whether or not Mork felt emotions.

Jonathan continued. "I don't know if it's a mistake that they don't mean to say that, that they don't have any emotions on Ork. They mentioned it in a few of them. . . .But a lot of times he feels sadness, mostly sadness, sometimes happiness. I would say trust. I don't know how much though. He sort of trusts his friends."

Then he presented the other side of the argument. "Ork is, the way I see it, so much more advanced that they don't have too much more emotion. And they just use computers. Like they probably for one thing don't have religion. And science is the only religion and like that. It's my view of Ork, they're probably so far advanced that they don't have even have emotions anymore."

So Jonathan was faced with an apparently unresolvable conflict. On the one hand, he knew from his experience with the show that Mork often expresses emotion. On the other hand, he felt committed to the theory that all Orkins, including Mork, lack emotions.

Jonathan expressed over and over his frustration with this conflict. "They don't try to use emotion but they use emotion anyway. It's almost impossible to make up a character with no emotions. It would be very hard."

And later. "Every place I think, Mork is showing an emotion but not as strong. If you look at it you say 'no emotion'. But when you think back on it, he has to be happy, sad, mad; he has to be something."

Even later. "He couldn't even tell jokes if he was neutral. When I think of someone with no emotion, I think of a serious person who talks like in one tone, and sits there all day like a. . . .It's hard to have no emotion."

For a while, Jonathan tried to avoid the problem by neglecting Aristotle's law of the excluded middle. In essence, he applied a method appropriate for a social conflict to an intellectual

one. He supposed that a compromise between incompatible propositions could constitute a solution.

Jonathan suggested that Mork's feelings were "not as strong. He's not as sad as a human would be. He's not as happy."

Eventually Jonathan and I discovered a real solution to his dilemma. I say 'Jonathan and I' because the solution emerged from a genuine intellectual collaboration. The crucial exchange occurred after Jonathan recalled a time when Mork "wasn't as mad as Mindy."

"What's your theory of why he wasn't as mad as Mindy?"

"Just that they originally had the idea that he would have no emotion. I guess they found that was impossible so they gave him a little emotion. But sometimes he doesn't show any. But you can tell he feels the emotion inside."

"Do you think they're changing the character as the show goes along?"

"Ya."

"Do you think that maybe the longer he lives on earth, the more human-like he becomes?"

"It's possible."

"You don't notice that in general he's becoming more human-like?"

"Well he's still doing his dialing the phone without using his finger. In emotions and feelings, he's becoming more human-like but not in acting."

In the midst of a collection of comments, Jonathan pointed out a difference between the way Mork was *originally* supposed to be and the way he *eventually* turned out. The statement could be interpreted two ways. First Jonathan could be finding a difference between the director's original conception of Mork and the actor's later interpretation of the character. Second he could be observing that Mork's personality evolved as the series progressed.

In my follow-up question, I assumed that the second meaning was intended. I asked explicitly whether he thought Mork was changing.

Jonathan in turn saw two interpretations to my question. I could mean that Mork's feelings

were changing or that his actions were changing. Jonathan agreed with the former but not with the latter.

Thus through clarifying the comments of the other person, Jonathan and I discovered an acceptable solution to his dilemma. We established first that Mork's action was realistic. And second we found that the question of Mork's emotions could not yield a simple 'yes' or 'no' solution. Yes Mork did in the end experience emotions. But no he did not always have emotions. He had no emotions when he lived on Ork. He had emotions now because he had learned them.

The theme of learning emotions became a frequent topic of conversation. In fact fictional realism was the only topic we discussed more. I will cite only three of Jonathan's comments. The first one concerns Mork himself.

"I liked the way Mork learned emotions. Were these six shows we saw in order from. . .like in chronological order? Ya I would think so because the way throughout them, he gets more and more emotions. How he's happy and he's sad for Mindy because she wants to go on a trip; happy for him and Mindy because they can go on a trip and sad for Mindy anyway because the trip turns out to be terrible. And then at the beginning, what was that beginning one with the puppy? Well in that one, Mork didn't really understand why he was giving him the puppy. . . .I think if they were going to have a new episode where they were giving someone a puppy, I think Mork would understand more why. I'm trying to think of one place where he gets mad. Right now Mork only gets sad and happy really. He's not mad or angry or . . . . He's only got two emotions, which are the two main emotions; he's sad sometime; he's happy; and he's neutral."

Jonathan mentioned how other characters' feelings changed as well. "In Mindy's father's case, when Mork first came he hated him. Mindy had to . . . . he almost didn't let her live with Mork. Finally she talked him into it. But now you get the idea, the more the show goes on throughout the year, the more he begins to like Mork."

Jonathan felt that Mr. Bickley was also changing. "I just got the idea he was getting nicer. In the

episodes I've seen the last few weeks, I can't really say if they're trying to make him nicer. I think they would be though. I think the people who write this show are very good writers. . . . You get to know the charcters more. He gets more feelings. He gets more human-like. Bickley gets nicer. It must be hard to write something where you have to make the characters so realistic."

Jonathan eventually discussed how the characters in other television series developed from week to week. Yet his most interesting comments concerned not the emotions of fictional characters but rather his own. By the seventh session, Jonathan was describing at some length how he thought his own emotions were changing.

The fact that the characters were changing from week to week was for Jonathan an important dimension of *Mork and Mindy*, important both intellectually and emotionally. He explained its importance by contrasting *Mork and Mindy* with another series, *Happy Days*. "Some shows like *Happy Days* and some of those shows, nothing happens. They just have a story each time. A new plot; a new story. But it doesn't build up. Like in *Mork and Mindy* somebody doesn't get more. . . .Gee I don't know how to explain it with *Happy Days*. It's just a new story and a new plot each time and you don't see the characters different each time. And you don't get as attached as *Mork and Mindy*. There aren't very many shows like *Mork and Mindy* where they can build it up. I don't know; I can't think of any offhand; it's hard. It must be hard; I'm surprised. I would think if they went to college and they took a writing course for TV shows they guy would mention 'you might want to do this or that.' I would think that would be one of the things they'd learn: that people would get more attached to the characters as they build them up."

Jonathan is making quite a clear statement about his own feeling. As he has seen the characters change, he has become more attached to the series. But following the characters is not the only experience that has made Jonathan feel 'attached'.

Jonathan described the effect of our conversations on his feelings for *Mork and Mindy*. "Like the things we've been talking about, I would know but I wouldn't be thinking about them.

Like I said before, *I'm getting more attached to the show by thinking about it* like this because there are things I would never have thought about which make it so the show is better. Every time I watch *Mork and Mindy*, I'll probably be thinking, not really about all the jokes like we did sometimes but general stuff like 'has Bickley got better', 'has Mork got more feelings'. I don't know. I should do it with more shows. (laughs). It makes it funner. I look forward to watching *Mork and Mindy*.

I wish to make two points about these last two quotations. The first quite obvious point is that Jonathan is making a psychological claim about his own emotional state. He claims to have a special emotional relationship with *Mork and Mindy*; his name for this relationship is *attachment*. The second less obvious point involves his style of making this claim. Both of these statements possess a self referential quality. Not only does Jonathan *say* he is attached but also in making these statements, he is *acting* attached. In other words, *these are the very statements one might expect from an attached person.*

[A statement can always convey meaning on many levels. Of immediate interest are two of these levels; I will call one of these levels 'the literal level' and the other 'the existential level'. On the literal level, a statement means whatever it denotes. The literal meaning of the statement 'I am attached' is straight-forward; it asserts that the being denoted by 'I' has the property of 'being attached'. On the existential level, the meaning of a statement is what it conveys about the speaker. The statement 'I am attached' conveys considerable meaning on this existential level. Among its existential meanings are that the speaker knows English (because the statement is made in English) and that he sometimes talks about his own emotions.

The existence of these two levels is of special interest in the case of self referential statements. The reason is this. In self referential statements, the literal meaning conveys information about the speaker. But since the existential meaning by definition conveys information about the speaker, these two levels can be compared with each other. We can evaluate the truth of one level by seeing if it is consistent with the other.

In Jonathan's case, the existential meaning tends to reinforce rather than undermine his literal meaning. Jonathan is claiming to be attached to *Mork and Mindy* in a way you might expect from an attached person.]

One sign of Jonathan's attachment is that he continually is praising the program. He praises it for its realism. "It must be hard," he said, "to write something where you have to make the characters so realistic." He praises the fact that the characters evolve. "There aren't many shows like

Mork and Mindy where they can build it up. I don't know. I can't think of any offhand. It's hard. It must be hard."

He praises the acting. "I like the way Robin Williams, the way he does his imitations. It must be hard to act out the part of Mork acting out the part of someone else. He has to play the role of Mork and the role of someone else. It's playing two roles at the same time. I think that's hard. . . .Especially if it's an imitation where you have to disguise their voice. You now act the other person. But I would say Robin Williams would have to be a very good actor to play **Mork**."

He praises the order in which I showed him the episodes. "I think where we ended was a good place to end. If I were never to watch *Mork and Mindy* again, I would get the idea 'Mork is. . . Mindy's father likes Mork. It's a perfect place to end where Bickley is pretty much better 'cause he's got his dog and Mindy's father likes Mork better and Mindy's grandmother always liked Mork. And Mork has got a few friends."

But most importantly and more persistently, he praises the effect of the research on his enjoyment of the program. I will list a few of these statements.

(1) "Seeing the program like this and talking about it makes you see the program better."

(2) "I should do it with more shows. It makes it funner. I look forward to watching *Mork and Mindy*."

(3) "I look forward to seeing it each week where I can remember what we did in the thing and think if it's realistic or not."

(4) "When I watch *Mork and Mindy* at home, I think about the things we talked about. I enjoy the show more really."

These last two comments provide a second sign of Jonathan's attachment. Jonathan reports that their search has affected his behaviour outside of the laboratory. The issues we discussed

became important themes for Jonathan in a variety of settings.

It is not surprising that these passed first from the laboratory sessions to the times when he watched *Mork and Mindy* at home. After we had finished the television study, Jonathan continued to discuss the episodes he had recently seen. One week he commented, "I was watching *Mork and Mindy* and they mentioned my idea. Mindy said how every week, or every day, Mork learns another emotion. And they had an idea how Mork didn't like having emotions. So it sort of followed my idea how every week Mork learns another emotion."

Another week he complained that the show was becoming less realistic. "Last week they had a haunted house. . . .It wasn't nearly what you would expect from *Mork and Mindy*. On *Mork and Mindy*, they're usually what could happen. You know it could happen but I doubt it. Really it wasn't too true."

Later seeing other television programs made him think about *Mork and Mindy*. One week, an incident in *Eight is Enough* reminded him of Mork's imitations. He was thinking "how it's hard for an actor to play another part and how like the imitations. And how some shows have a lot of jokes and no real story line, and other shows have a real story line. . . .On *Eight is Enough* a few weeks ago, they had one of the girls get up on stage and play a part in a play."

Once a movie reminded him of our discussions. "I was just thinking about 'is it factual'."

Jonathan displayed the very behavior one would expect an emotional involvement to cause. He watched *Mork and Mindy* whenever he could. He liked to talk about it and to think about it. He used the program as a standard by which to judge other television programs. He had the highest praise for the show itself, for the people who present it and for the experimenter who discusses it with him. Given this complex of behaviour, it would seem hard to dispute Jonathan's own self-analysis: he had indeed become attached to *Mork and Mindy*. Following Jonathan's own usage, we may use the term 'attachment' to designate the emotion he felt toward *Mork and Mindy*.

Most of the evidence of Jonathan's attachment to *Mork and Mindy* came after he had seen

all six of the video-taped episodes. It was only during the seventh session that Jonathan described himself as 'attached' or that he used *Mork and Mindy* as a reference point for analysing other television series. During the earliest sessions, Jonathan did show some signs of emotional involvement. But before the seventh week, the object of his attachment was not the series *Mork and Mindy* but rather its protagonist, Mork.

During the third session, I asked Jonathan, "Did you feel sad when Mork felt sad and did you feel happy when Mork felt happy?"

"Ya, I was sad for him and happy for him. That's what TV shows do. When there's a sad scene, you feel sad and when there's a happy scene, you feel happy. That's why people watch soap operas, to get sad."

I asked him if he felt the same way about Mindy as about Mork. He answered, "I think of it as Mork. Mindy has almost as big a part as Mork but Mork has most of the lines, the funny lines. He's the show. If there was no Mindy, you could have the show; you could get a replacement. If there was no Mork, you couldn't have the show."

"I get a little more sad because of Mork. You get attached to the person. But when Mindy is sad and Mork is there, he tells a lot of jokes to try to cheer her up. And it cheers you up but it doesn't cheer her up. So it works on you. But I would have felt pretty sad if Mork was sad."

Jonathan elaborated on his feelings toward Mork. "When you like him, it's sort of like being a friend. Or listening to the jokes, just the fact you like him makes him funnier to you, a better person to you. If you don't like him, he would seem like a not very good person and his jokes wouldn't seem as good."

In these comments, Jonathan is expressing a considerable degree of attachment to Mork, He is saying not only that he likes Mork but further that he perceives Mork as a friend. In fact, during this conversation, Jonathan used the concept of 'attachment' for the first time to describe his own feelings, when he observed that "you get attached to the person" [Mork]. Jonathan's description of

his own emotional reactions confirm that he felt involved with Mork. He noticed that he had felt sad when Mork was sad and happy when Mork was happy. Furthermore his reaction to Mork's feelings was more intense than the common sympathy he might feel for any human being. As Jonathan himself observed, he reacted more strongly to Mork's feelings because he liked him. When Mindy became sad, Jonathan was not affected as much as when Mork was sad.

During the same conversation, Jonathan compared his feelings toward Mork with his feelings toward Mr. Bickley. "Let me go back to the one with the puppy. I felt a little sorry for him the way he was lonely. And I felt happy for him when he got the dog. Not for him, but for Mork and Mindy 'cause they had given it to him. And that now he was happy and he wasn't going to bother anybody. So I felt happy then. But when he was lonely, I felt a little sad but not very much since he was pretty mean."

He explained why he reacted more strongly to Mork's emotions than to Bickley's. "You like Mork better. You like the character Mork more than you like the character Bickley. He's funny. He has a better character. Bickley's a mean grouch. Mork's a nice funny person; so you would like him better."

In this conversation, Jonathan's reaction to the character, Mork, displays the same symptoms of attachment as does his later reaction to the series, *Mork and Mindy*. Just as later he praised the series as a whole, at this point he praised Mork's personality. Just as later he described himself as 'attached' to the program, in the conversation he said he was 'attached' to the person. Furthermore, just as later he used *Mork and Mindy* as a standard against which to compare other television series, in this session he used Mork as a standard against which to compare other characters.

But the important point is that Jonathan acquired a new object of attachment between the third and seventh sessions. In the third session, we have evidence only that he was attached to Mork. By the seventh session, however, Jonathan displayed an attachment to the series as well as to the

character. Thus we observe an analogy between the development of Jonathan's knowledge and the growth of his feelings. In our discussion of fictional realism, we observed a change in the class of potentially realistic objects. During the third session, Jonathan applied the concept of fictional realism only to individual incidents and characters; however by the seventh session, he applied this concept also to *Mork and Mindy* episodes and television series. But while the class of potentially realistic objects was growing, so was Jonathan acquiring a new object of attachment. When he considered the realism only of individual characters, he was attached to a character, Mork. But later when he considered the realism of entire television series, he was attached to a television series. Thus *the development of the concept of fictional realism proceeded in parallel with the establishment of new attachments*. The existence of such a parallel provides evidence that the change in Jonathan's knowledge was related to the change in his feelings.

After the seventh session, Jonathan began to watch *Mork and Mindy* regularly and more significantly to think about the program while he was watching it. We can trace the effects of his reflection on the growing complexity of his opinions.

You recall that Jonathan originally found the caterpillar episode quite realistic. He said, "That was the most realistic, more than the other ones. . . .It was all about a caterpillar changing into a butterfly. They didn't realise it was changing into a butterfly. They thought it was dead."

Jonathan went on to isolate the realistic element. "The idea was Mork gets a pet caterpillar and the caterpillar starts changing into a butterfly. And it probably looks dead when it does that or something. And so Mork thought the caterpillar was dead."

So Jonathan found the episode realistic because of Mork's interpretation of the caterpillar's metamorphosis. Jonathan thought that an insect might genuinely appear dead at such a time.

Three weeks later, I asked Jonathan if he found the caterpillar story realistic. "The one with the caterpillar, the idea that he's going to put a caterpillar in a box and take it as a pet. . .Mork's character wouldn't take a caterpillar as a pet. He probably wouldn't know what a caterpillar is. But

getting back to the point, the caterpillar one would happen maybe one percent of the time. I doubt that Mork's character would take a pet caterpillar as a pet. So they're all realistic; they all could happen, easily. But it's not; I don't think it would happen."

Over a three week period, Jonathan seemed to have lowered his opinion of the episode. At first he thought it was the most realistic. Now although he still considered it somewhat realistic, he did not really think it would happen.

After another two weeks, we discussed the caterpillar episode for a third time. By this point, Jonathan had distinguished between a realistic part of the program and an unrealistic part. "First the non-realistic part is that Mork's going to pick up a caterpillar and take it as a pet."

"That's the idea I'm saying now. That Mork might not know to pick up a caterpillar and take it as a pet. He might not even know what a caterpillar is. You usually just see a caterpillar sitting on the ground. He wouldn't know what it was. So it's not likely, as you said, that he'd take it as a pet."

"It's not very likely he's going to get the caterpillar, but once he gets the caterpillar, that might be the way the story goes. That it builds a cocoon and turns into a butterfly."

By the end, Jonathan had succeeded in synthesising his two earlier judgments. During the earlier sessions, he felt obliged to label the story as either realistic or unrealistic. During this session, he could say that one part of it was realistic but another was unrealistic.

The important point is not simply that his judgment had become more sophisticated but rather the conditions under which it changed. During the research sessions, we never discussed at length the realism of this episode. So the impetus for revising this opinion could not have come from our conversations. It must therefore have come from Jonathan's own thinking outside of the research.

A more dramatic change was in Jonathan's description of the second episode. This was the program when Mindy sent Mork to a basketball game so she could spend an evening alone with a

boyfriend. While Mindy and her friend were embracing, Mork arrived, disrupting the atmosphere and embarrassing Mindy. The boyfriend beat a hasty exit, expressing horror that Mindy would date him while living with another man, leaving Mindy alone in tears. The next morning, in place of Mork, Mindy found the following letter.

Dear Mindy,

I know you are sad because people think you and I are lovelings. I don't want you to be sad anymore, so I'm going away. If people on Ork knew how to love, I'm sure I would love you. I don't even know what love is.

love,

Mork

Immediately after the program, Jonathan thought that Mork had run away because he felt he had been embarrassing Mindy. "It was one idea of him feeling not wanted and running away. . . .Feeling that he's unwanted because he's different and running away."

For Jonathan, the main cause of Mindy's distress was Mork's strangeness. She was embarrassed by Mork's eccentricity in front of her friend. Jonathan does not understand that even a very conventional man in Mork's position would have been just as disruptive. The boyfriend left, not mainly because Mork was strange but rather because Mindy was living with a man.

Five weeks later, Jonathan's opinion had not changed. In a discussion of realism, Jonathan recalls, "The main idea was that he does some things wrong and she gets mad at him. And then he runs away." Jonathan still considers Mork's misconduct to be the ultimate cause of his running away.

After another five weeks, when Jonathan could not have seen the program within two and a half months, we discussed the incident again.

"Do you remember the episode where Mork ran away from home?"

"Ya."

"Do you think that was pretty factual?"

"Well that's only realistic. The reason he runs away, running away from home could be factual. The reasons he runs away from home are factual for the characters."

"What was the reason why he ran away from home?"

"He was bothering Mindy by living with her. You know because Mindy's boyfriends would leave when they saw Mork.

Jonathan no longer refers to the irrelevant fact that Mork behaved strangely. He says simply and correctly, Mork was bothering Mindy by living with her.

I told Jonathan that another subject had used Mork's weirdness as an explanation for running away. He thought Mork felt unwanted because he was different, and therefore he ran away. Jonathan answered: "It could be anybody in the whole world almost and the boyfriends would still leave her. It could be...no it couldn't be her father. But it could be her cousin. The boyfriends still wouldn't want to stay with her. Because they'd think she was living with him. They would think she was living with him and they're not really friends and she's probably married or something. You know that they're going to get married and there's no use going out with her. So it could be anyone in the world; he wouldn't be different."

"So you think the idea 'he felt unwanted because he was different; so he ran away', that's a very odd interpretation?"

"Well it's still possible but it's not the best thing to say about it."

As these two scenarios illustrate, Jonathan's attachment to *Mork and Mindy* made him think at length about the series. And because he thought so much, his interpretation of the series became more sophisticated. One should not however conclude that the main effect of Jonathan's attachment was on the quantity of his thinking. On the contrary, Jonathan's attachment was most influential when it determined the direction as well as the magnitude of his learning.

From his experience in *Mork and Mindy* World, Jonathan acquired knowledge useful in

contexts far broader than the discussion of one particular television program. Although he first discovered the themes of 'realism' and 'emotion learning' from his analysis of *Mork and Mindy*, he ultimately extended them to works of fiction unrelated to television. Because these concepts could prove generally useful outside of the classroom, they represent genuinely valuable intellectual achievements. We should therefore consider the acquisition of these themes to be Jonathan's most significant learning. And we should see his attachments as important because they led to the development of these two themes.

You will recall that 'fictional realism' and 'emotion learning' both emerged at the end of rather lengthy discussions. Jonathan raised the question of Mork's realism as a result of his analysis during the second session of the basketball joke. During the fourth session, Jonathan proposed the concept of 'emotion learning' to explain why Mork had accused Mindy's friends of stealing her necklace. Let us now reconsider the theft incident from the viewpoint of Jonathan's emotions.

The difficult issue for Jonathan was deciding if Mork felt emotions. On the one hand, they say that Orkins, such as Mork, feel no emotions; on the other hand, many of Mork's actions clearly reflect some emotion.

Jonathan expressed increasing frustration with the program for claiming that Mork feels no emotions. "They don't try to use emotion but they use emotion anyway. It's almost impossible to make up a character with no emotions."

A few minutes later he returned to the same complaint. "He couldn't even tell jokes if he was neutral. . . .It's hard to have no emotions."

These complaints seem to express a resolution of the conflict. They insist over and over again that Mork does feel emotions. At this point, Jonathan should therefore abandon the issue. He should conclude that Orkins do indeed feel emotions and that any statement to the contrary is a fabrication. But he does not abandon the issue. Rather he keeps reviewing the same arguments with tenacious repetitiveness.

Why does he keep going? His actions appear incomprehensible if you think he wants only to resolve his conflict. Clearly he has an easy resolution and he chooses not to adopt it. We must therefore assume that he has some other goal more powerful than his wish to resolve the conflict.

We gain some understanding of this higher goal from Jonathan's unsuccessful compromise solution. He suggested that Mork has feelings but they are not as strong as human feelings. "He's not as sad as a human would be. He's not as happy."

Despite his words, Jonathan shows a persisting loyalty to both sides of his conflict. He is not prepared to allow that either side is completely wrong. The invention of this compromise reveals his divided loyalty. A compromise is attractive because it finesses the problem of choosing sides.

This conversation provided a complex experience for Jonathan. Before discovering his final synthesis, Jonathan passed through many emotional states. He began feeling confident that Mork experienced no emotions; next he became frustrated when he could not resolve his conflict; finally his tension dissolved when he found a synthetic solution. Simultaneously, Jonathan was engaged in intense thought. It is difficult to know which components of this experience contributed to his ultimate emotional attachment and which were irrelevant.

The basketball joke and the accusation incident both had the effect of undermining a premise built into Jonathan's original frame of reference. The basketball joke revealed the complex relationship between Mork's psychology and the psychology of real human beings. Although Mork did not act exactly like a human being, neither was his behaviour governed by forces totally alien to human psychology. The accusation incident undermined Jonathan's confidence that Mork felt no emotions. Mork's actions proved that he felt some emotions but these were not exactly the same emotions as people feel.

The irony of course is that this short-term uncertainty led ultimately to an increase in Jonathan's self-confidence. After first questioning his basic assumptions, Jonathan proceeded to alter his premises; the effect of this reformulation was to make Jonathan more convinced than ever of his

revised frame of reference.

For Jonathan, the discovery of a theme ended a long period of intense reflection. The experience may have been happy because it relieved the frustration of feeling uncertain. Or it may have been sad in ending the pleasure of concentrated thought. But whatever its immediate effect on his mood, the discovery of a new theme ultimately enriched Jonathan's life both intellectually and emotionally. Intellectually, the new themes enabled him to notice features of fictional works which would previously have escaped his attention. Emotionally, they taught Jonathan new feeling toward *Mork and Mindy* of interest, respect and attachment.

4. Toby

Like Jonathan, Toby enjoyed the incident where Mork accused Mindy's friends of having stolen her necklace. But Toby never raised the literary question which interested Jonathan. He did not wonder if Mork's accusation was in character for him. For Toby, the event was interesting from a social and not a psychological point of view. It raised the question of why groundless accusations are in bad taste.

"Well you don't usually call people and accuse them of doing something." He continued. "You don't say, 'Did you steal Mindy's necklace?' You might work at it gradually saying 'Mindy can't find her necklace. I wonder if you picked it up by accident' or something. And he just says 'Did you steal Mindy's necklace?' and she tells him to blow it out of his ear."

"It's not polite and someone's not just going to tell you, 'Ya I did steal her necklace.' It's not polite. Just going up to somebody and saying, 'Did you steal her necklace?' It's not polite."

I asked if it would bother him for someone to accuse him of theft. "Well Marc always says, 'Toby did you steal my pen' and looks in my cubby and stuff. It bothers me....I just don't like it. He always accuses me of it."

Marc is another boy in Toby's class. The two of them are supposedly best friends. Early in the school year, Toby's sixth grade teacher told me how she was impressed by their friendship. When they worked together, she found, they produced strikingly creative ideas. Later in the conversation, she added that Marc provided the creativity. Toby is less flamboyant; he is more stable and reliable. "Toby is best at subjects that require little imagination, like mathematics."

Unlike Mork, Toby is polite. I never saw him express an opinion without first thinking how it would affect other people. On the other hand, he often acted with the express intention of impressing someone. These efforts did not always succeed.

Jonathan was uninhibited in his enthusiasm for the research. Not only his words but also

his actions expressed the strength of his commitment. Because he enjoyed the Chemicals World, Jonathan requested, and received, a Chemistry set for Chanukah. Also toward the end of the chemicals research, Jonathan's parents wanted to stop driving him each week to Harvard. Jonathan provoked an argument over his right to continue seeing me. In the end, they agreed that Jonathan would come by subway, even though his parents did not like him returning home alone after the early mid-winter sunset.

I had initially planned for all three children to spend six weeks working in the Chemicals World. At the end of six weeks, I had become impressed by the originality of Toby's work and wanted to see what experiments he would devise given a little more time. Because Toby worked so attentively I assumed that he enjoyed the research and would want to continue longer. So I proposed to both Toby and his teacher that we delay the television study for two weeks and continue the chemicals study in the meantime. His teacher had no objections. She felt the research was valuable both for Toby and in its own right. She was willing to have Toby miss the extra class-time. Toby also had no objections but neither did he express enthusiasm for the idea. He would be happy to work at chemicals or television, whatever pleased me.

After two more sessions with the chemicals, I again raised the question of continuing the study even longer. I asked him, "Do you want to have the television program or work more with the chemicals?"

"I don't know."

"It's okay with you both ways?"

"M hm."

I continued to ask him about his reaction the research. "I'd also like to know if you've generally found it interesting to work with these chemicals."

"M hm."

"Are there specific chemicals or specific experiments you found most interesting?"

"Sulfur and sodium iodate. And the purple smoke."

A while later, Toby thought of another interesting chemical. "Baking soda. Well an acid and a base."

"Are acids and bases interesting?"

"Ya."

"But not as interesting as sulfur and sodium iodate?"

"M hm."

"Are the other chemicals very interesting?"

"They're all interesting."

"What about cuprous oxide? Is that interesting?"

"Is that the purple stuff?"

"Ya."

"I don't like it. 'Cause it makes everything all powdery."

" What about bleach? Do you like it?"

"Ya. 'Cause it takes away colour."

"What about food colouring? Do you like it? "

"Ya. It's the food colour that the bleach takes away."

It is relatively easy to offer a crude demonstration that Toby had very definite preferences for certain chemicals. One rough measure of his preference is the number of times he used each chemical. Since most of his experiments involved mixing and heating chemicals, it is possible to count the times he added a new chemical to a mixture.

Over the eight weeks, Toby added a chemical 261 times. Those 261 pourings were distributed among 23 chemicals, 22 that I provided and one, a live insect, that Toby himself found in the research room. Assuming that he had no preferences, you would expect him to have used each chemical 261 / 23 = 11.3 times. In fact, he used certain chemicals much more often than that. A

good example is bleach which he used 39 times.

Furthermore, again assuming no preferences on his part, you would expect any given pair of chemicals to have been added quite rarely in immediate succession, one after the other. Since there were 23 chemicals, Toby therefore had 23 x 23 = 529 possible pairs of chemicals. If he had been acting randomly, he would have used few of these pairs even twice. But in fact he mixed vinegar, his acid with baking soda, his base, a total of 15 times. His favourite pair of chemicals, sodium iodate and sulfur, he combined 24 times in immediate succession.

These frequencies can be analysed statistically using *student's t test*. In all three cases (bleach, vinegar plus baking soda, sodium iodate plus sulfur), the results are astronomically significant, well beyond the .001 level. We can feel free to conclude that Toby had very definite preferences for certain chemicals. Not surprisingly, these are the same chemicals that he claimed to prefer when we discussed the question of preference.

At certain times, Toby expressed his feelings more passionately than at others. The session before our discussion of preferences, a group of Toby's classmates intruded into a research session. In front of his peers, Toby expressed the same feelings as he did alone but with slightly less reticence.

After I had allowed his classmates to stay in the research room, Toby asked them, "What should I do?"

"I think you should put some pure honey into it. That will make it bubble," suggested one boy.

"Do you have any iodine?" asked another.

"How about some explosives? Do you have any fireworks crackers?" added a third.

Toby added some sulfur to an empty test tube. "Put baking soda in there. That will get it bubbling," continued the first boy.

Toby added sodium iodate to the sulfur and then held the test tube over the bunsen burner. He turned on the flame.

"It'll blow up the building."

"I bet it'll shatter."

"It'll melt. The thing's going to..."

"Oh I swear. Oh excellent. Look at that. Okay. Enough Toby."

"Call the fire department."

As yellow smoke began rising from the test tube, Toby calmly turned off the heat. Then he told his classmates, "This is how I make the smell."

"Oh pew. How could you not hold your nose?" demanded a fourth child. "Listen to it. Alright it's ready to blow up the school."

One child pointed to the cuprous oxide. "This," he indicated for Toby to add the compound to his mixture. "Not that," Toby answered. "Is that the purple stuff? I hate that stuff."

"Graphite powder" suggested another boy. Toby added the graphite to an empty test tube. "It smells like a fire cracker. No it smells like a smoke bomb."

Toby ignored the heckle. "It needs something else."

"Vinegar."

"Except it's not going to be liquid."

"Sulfur."

"Salt." Toby added some table salt to the graphite powder. "I've never done this before. So you guys better watch out."

Toby turned on the bunsen burner to heat his mixture.

"I smell glue."

"Toby you know you'll have to pay for this."

Toby turned off the bunsen burner. Since the session had by then officially ended, I intervened. "I think we better clean up."

Toby wanted to perform one more experiment. He added sulfur and sodium iodate to an

empty test tube, placed the test tube over the bunsen burner and turned on the flame. "This is my favourite experiment."

Purple iodine gas started rushing out of the test tube. "Look at that," said the first boy. "It's a bloody Mary."

"What is that coming out? Ah neat."

"It was excellent. Neat."

A flame ignited inside the test tube. Toby turned off the bunsen burner and placed the test tube upside down onto the table. A few moments later he raised the test tube to reveal a black sludge.

It is clear from both Toby's words and actions that he feels a definite attachment to certain reactions. He says that the mixture of sulfur and sodium iodate is his 'favourite experiment'. And he treats the reaction the way you would expect him to treat a favourite. He makes a point of sharing this discovery with his peers and he tells them explicitly how much he likes it. Toby's enthusiasm for sulfur and sodium iodate is like Jonathan's praise of the writing and acting in *Mork and Mindy*. Both boys express enthusiasm verbally for objects which appear, on independent grounds, to be the focus of their attachment.

The same reasoning which previously implied that Jonathan was attached to *Mork and Mindy* should now argue that Toby was attached to sulfur and sodium iodate. Toby's treatment of sulfur and sodium iodate revealed almost the same symptoms of attachment as Jonathan displayed. Just as Jonathan thought frequently about *Mork and Mindy*, so did Toby experiment often with sulfur and sodium iodate. Just as Jonathan would praise the television program to me, so would Toby "show off" his chemicals to his classmates. Just as one boy said explicitly that he was attached, so did the other confess sulfur and sodium iodate to be his favourite chemicals.

Like Jonathan, Toby revealed his involvement in the research through the intensity of his work. Just as Jonathan could lose himself thinking about *Mork and Mindy*, so could Toby have lost

himself in his work with chemicals. But there was a difference in their styles of involvement. While Jonathan became involved in theorizing about *Mork and Mindy*, Toby engaged himself in physically manipulating chemicals. In spite of this difference, Toby's behavior revealed both concentration and freshness of thinking, just as Jonathan's did. Consider this episode from the fourth session as example of Toby's investigative style.

Toward the middle of the session, Toby noticed a bee near the windowsill. He picked up a rag and went over to the bee. I asked Toby, "Is it dead?"

"Pretty much. He's going to become an experiment."

With his left hand, Toby grabbed the bee in the rag. He carried it to the table, took the tongs in his right hand, and transferred the bee to the tongs. Then he placed the bee into a test tube. He inspected the bee closely. "The stinger, it's on the back."

Toby added some green food colouring to the test tube. "This is sort of mean. I don't know if it's quite dead yet."

He took a stick and jabbed the bee. Then he added bleach to his test tube. "Now I'm going to burn it."

Toby placed the test tube over the bunsen burner and heated the mixture for a few seconds. After he turned off the heat, he described what he had observed. "All the green started turning yellow and then it turned white; I guess the bleach was taking away the colour. Then it all evaporated." He added that part of the mixture did not evaporate. Pointing to the bottom of the test tube, he noted, "The bee is stuck in that gunk down there."

Toby poured the bee from the test tube into a beaker of water. "He's sort of see-through. Sort of. He's already dead."

He poked a pencil into the bee's abdomen. "Now this is filled with the stuff that...I think that's where he stores his...whatever, you know when they sting you, the stuff they put into you. At the end of there is where he stores that. Or is it the pollen at the end?"

By this time, the green food colouring from the bee had begun to dissolve in the water. Toby placed the bee along with a fly he had noticed into his test tube. He poured some of the green water over them. Then he added sodium iodate.

I asked him, "How did you get the idea of putting the bee in the test tube?"

"I don't know." He continued, "Because I thought it would be good. I don't know; I didn't know what it was at first. I just heard it. Then I went over to get it for an experiment."

That was how Toby usually worked. Instead of following some set plan, Toby liked to improvise on the basis of chance observations. This openness to accident kept his ideas fresh since the most surprising and therefore exciting phenomena were the ones he could not predict. Through one of his accidents, Toby discovered the purple smoke to which he eventually became attached.

Toby heated his greenish mixture. While it was hot, he poured it into a plastic cup where it began to turn yellow. Next he poured a few drops of this presently yellow liquid onto a paper towel, which then turned blue. Finally he poured some bleach on the blue stains, and immediately the colour vanished. Then Toby announced, "I have an idea."

He threw away the paper towel he had been using. Then he covered a fresh paper towel with the yellow liquid so that it became completely blue. He dipped the eraser end of his pencil into the bottle of bleach. With the bleach-covered pencil, he started to erase the letters of his name on the blue paper towel. In the end, the negative space created by selective bleaching spelled 'T-o-b-y' against a blue background.

This episode represents a stage in Toby's involvement comparable to the opening session with Jonathan. There is no evidence that Toby is attached to the bee. On the contrary, such an attachment seems most unlikely because Toby had never worked before with a bee in the research. But like *Mork and Mindy* for Jonathan, the bee provided Toby with an object he could use.

Jonathan, you will recall, first became interested in *Mork and Mindy* because the program seemed to fit his intellectual style. It was Jonathan's style to apply general theories to particular

events. Since *Mork and Mindy* provided both salient events and theories to explain them, it gave Jonathan the chance to do something he liked. He was able to manipulate theories. Similarly, the bee fit Toby's intellectual style. Toby liked to manipulate familiar objects to produce novel results. Thus he enjoyed treating the bee as if it were a chemical, even though within Toby's experience bees no more were chemicals than flamingos are croquet mallets. Later, he used the compounds extracted from the bee's body as components of a dye for colouring a paper towel.

His work with the bee led Toby to notice other objects which could be manipulated in unfamiliar ways. He noticed that you could write 'negatively' as well as 'positively'. Words appear not only when you place 'ink' onto a blank background but also when you create black spaces on an inky background.

Just as Jonathan's thinking eventually showed qualitative changes, so did Toby's. Furthermore the intellectual progress of both boys seemed to follow the same pattern. At the beginning, their attention was held by a micro-world appropriate for their own intellectual styles. Once they had become interested, certain key experiences served to undermine their initial impression of the micro-world. Through thinking about these key experiences, they achieved knowledge about components of the micro-world. And a side effect of their deepening knowledge was to become attached to these components.

But there was one notable difference between Jonathan and Toby in the way their thinking changed: while Jonathan acquired new theories, Toby acquired new actions. Through the act of theorising, Jonathan naturally developed new theories which could later be applied in future theorising. Similarly, through the act of manipulating, Toby would naturally develop new procedures which can later be applied in future manipulations.

At the beginning of the research, I did not realise how important a child's temperament could be. Nor for that matter did I suspect that the theory/action dichotomy would provide a basis for distinguishing different intellectual styles. So I began my first session with Toby suggesting a task

which I now recognise as totally inappropriate. One reason why Toby learned so much is that he had the courage to ignore my suggestion.

I opened the first session with the following speech. "You can do anything you want with the material. I'm interested in how you discover things for yourself. I'll give you an idea of the kind of thing you might find interesting."

I took some sugar and poured it into a test tube. Then I asked Toby to watch as I heated the sugar. When the experiment was over, Toby described what he had observed. "The sugar sort of started lifting up in the test tube and then it turned black and a lot of smoke came out and then it flamed."

I tried to make Toby speculate on why the reaction had happened. His only idea was that "when the sugar got heated, the carbon dioxide came out." He thought, "Inside the sugar grains, there's a teeny teeny space with carbon dioxide inside it. I don't know. You can't see the carbon dioxide."

For twenty minutes, I tried to engage Toby in a discussion about the sugar reaction. I asked how he knew the carbon dioxide was in the sugar; whether the carbon dioxide might be in the fire and not in the sugar; what he thought made the sugar burst into flames; why you cannot see the carbon dioxide when you look at the sugar; and many similar questions. None of these questions stimulated very much interest. In answer to the first question, Toby said he just knew the carbon dioxide was there. He could give no further justification. Toby conceded that the carbon dioxide might be in the fire instead of the sugar. He thought the sugar burst into flames because of the heat. And you cannot see the carbon dioxide because it is a chemical.

During the remainder of that school year, Toby religiously avoided sugar in all of his experiments. The first time he used the sugar was the following September during the seventh session four months after. I asked him then if he had ever used the sugar before. He answered, "Yes, the first time." The answer did not allow the possibility that he may also have used it on other

occasions. I suspect therefore that he had been intentionally avoiding it.

After finishing the discussion about sugar, Toby looked over the collection of chemicals. "I know something." He took the vinegar and the baking soda. "You can put these together. And after it will fizz."

He took a test tube and added first baking soda and then vinegar. The solution fizzed. "What's this?"

"It's sulfur."

"Chlorox bleach. Dirt. Lead metal. Graphite. Oxide red. What would happen if you burned this?"

Toby was holding the test tube. "Do you want to?"

"I guess so."

He poured his mixture into a beaker, placed the beaker on the tripod and turned on the bunsen burner. "It's fizzing again. It's just boiling. The baking soda is burning; it's all black. The vinegar's bubbling."

Toby turned off the heat. "There's some white stuff in there. Maybe that just didn't burn. It smells sort of like yeast."

He added more baking soda to the mixture. "It'll fizz in a moment." It starts to fizz. "Weird!"

After this first experiment, Toby continued experimenting with the bunsen burner. His next variation was to heat a substance he had seen, but never in the context of Chemistry. He poured some dirt into a test tube and heated it. He noted his observation. "It turned black, brown and grey."

In his third experiment, Toby chose two unfamiliar chemicals. First he picked up the jar of sulfur. "Can I take some?"

"Sure."

"Can I mix it with sodium?"

"Yes."

Toby added first sulfur and then sodium iodate to a fresh test tube. "Now some salt." He poured table salt into his mixture. "And now I burn it." He shook the test tube, placed it over the bunsen burner and turned on the flame. A few seconds later he turned the heat off.

"It's turning black. Now it's purple smoke coming out. It's burning more; more smoke and stuff. It's making the test tube purple. Not the very top. The bottom part is dark purple. The bottom is sort of black."

"The very bottom looks white."

"Ya the bottom is white." A few moments later, he asked, "Can I pour this out?"

Toby begins to tilt the test tube. "Purple steam is coming out."

"Why did that happen?"

"I don't know. 'Cause it burnt right through the sides probably. I'm going to add water to this." He adds water and more steam escapes. "All the steam...purple. The water turns yellow. I'm going to heat it again."

He turned on the bunsen burner. "It's going more purple. The steam is turning. But down in the bottom, it's boiling; a lot of purple steam is coming. Oh it's jumping out of my hand."

The purple steam was the same chemical which Toby eventually called 'my purple smoke'. This compound, iodine gas, was Toby's most obvious attachment object. Because this experiment led Toby to notice iodine gas for the first time, its ultimate significance is great. However this significance is not immediately apparent. We can only see its importance by knowing its long term consequence.

Next Toby turned off the flame. He placed the test tube into the beaker of water. Suddenly more purple gas rose out of the test tube.

"What made all the smoke come out?"

"I think it's the sulfur that did that."

"Is there any way to find out?"

"Heat the sulfur alone. Can I use the same test tube?"

"Okay. You want to heat the sodium iodate alone?"

"No the sulfur alone. It's yellow. It's already a colour."

Of his three chemicals, sodium iodate and table salt are both white but sulfur is yellow. Toby evidently thought that yellow is a colour but white is not. Furthermore, he seemed to think that colourfulness is conserved during combustion even if the specific colour changes. He was led to conclude that the only 'colourful' chemical, sulfur, caused the purple smoke.

Toby poured some sulfur into a test tube. He heated it. "Just the sulfur it makes yellow smoke."

This first attempt to produce purple smoke thus failed. But the failure was not a total loss. Toby added sodium iodate to the hot test tube of sulfur and the mixture changed colour.

"All of a sudden it turned purple. I'll add salt now. I don't think anything will happen." He added the salt. "Maybe a little more purple. I think this makes the purple smoke though." He was holding the sulfur and the sodium iodate.

Toby's new theory asserted that the purple smoke was produced by the combination of sodium iodate and sulfur. Toby retained this belief for the entire experiment. The theory was correct in the sense that the mixture of these two chemicals did produce iodine gas when heated. But it was unparsimonious because the sulfur in fact was superfluous. If you heat sodium iodate in isolation, you will produce the same purple iodine gas.

Toby's next experiment made use of the chemical theory. In a fresh test tube, he mixed table salt, sodium iodate, sulfur and yellow food colouring. "Okay, I bet it still turns purple."

He placed the test tube over the heat and turned on the flame. "Nothing's happening. There's still purple smoke."

'Nothing' for Toby was nothing unexpected. A confirmation of his theory was for Toby a non-event. But from this experiment, he did make one new observation which later would prove important. "It smells. It's the smoke or something. I don't know. It just smells."

Toby followed his conservation of colourfulness theory in conducting his next experiment. "I'm going to make a mixture of these two: graphite powder and cuprous oxide." He opened the cuprous oxide jar. "Weird. It's purple. It might make purple smoke again."

Toby poured some cuprous oxide into a test tube. Then he added graphite powder and phenolphthalein and heated the mixture. Toby noticed some yellow smoke but no purple gas. "They mixed together and when they're heated, smoke comes out and it's yellow. I don't know how come it's yellow. I think it would have been purple if we had used only the one I said was weird, that was purple."

This last comment shows that Toby has not only retained his conservation of colourfulness theory but in fact has strengthened it. He believes not only that colourfulness is conserved during combustion but even the specific colour. He expected that the combustion of a purple powder, cuprous oxide, would yield a purple smoke. Note however that Toby never insisted on testing his theory. He asserted that cuprous oxide would make a purple smoke if heated in isolation but he did not evaluate this hypothesis experimentally.

Just as Jonathan had generalised the concept of fictional realism to an increasingly broad range of contexts, so did Toby create his purple smoke in a variety of situations. This generalisation began early in the second session.

During the opening sessions in the chemicals world, Toby, like Jonathan and Leonardo, introduced a variety of chemicals in his experiments. Of the 23 chemicals, Toby tried 19 during the first two sessions. One typical procedure, discovered by Leonardo as well as Toby, was to mix them all together in one big experiment. One such 'mega-mixture' provided the first new context for making purple smoke.

The experiment in question involved the first of Toby's mega-mixtures. At the beginning of the session, Toby had combined lead metal with cuprous oxide, sodium iodate and bleach. Next he added this first mixture to a beaker containing phenolphthalein and more sodium iodate. Then this second mixture was combined with vinegar and soap. When Toby thought of making purple smoke, he was in the process of heating this last mixture. The result did not seem to interest him especially. The mixture was boiling; but otherwise Toby noticed nothing unusual. At this point he announced, "Now I'm going to add sulfur."

He added some sulfur to the boiling mixture. "There's purple smoke coming up now. It should be more now. More purple smoke. A little I guess. Okay stop." He turned off the heat.

I asked him, "Why did you think there'd be a lot more purple smoke when you added the sulfur?"

"Because the last time I added sulfur, there was purple smoke. With sodium iodate."

"Was there any sodium iodate in there?"

"That's why there was purple smoke."

"So what makes purple smoke?"

"Sodium iodate and the sulfur."

This episode makes one fact clear. Unlike the first session, Toby no longer considered that colour might be conserved in a chemical reaction. It was the reagents themselves, and not their colour, which caused the colourful gas.

But this incident is more significant as a symptom of Toby's growing relationship with the purple gas. During the first session, Toby created his purple smoke just for the intrinsic interest of seeing and controlling the reaction. He had no larger ulterior motive. But now, he was using his knowledge of the reaction instrumentally. He was producing his purple smoke to salvage a failing experiment. Just as Jonathan thought about Mork first for his own sake and late as point of reference to analyse other television characters, so was Toby's use of purple smoke acquiring new functions.

Toby made purple smoke first for its own sake and now as an aid in getting pleasing effects from other chemicals.

In his next experiment, Toby mixed vinegar with bleach and sulfur. Before heating the mixture, Toby promised, "I'm going to add sodium iodate and see if it makes purple smoke. I think it might make yellow smoke now."

"Because sulfur alone makes yellow smoke or because sulfur with the things you have in there makes yellow smoke?"

"Because sulfur makes yellow smoke?"

Before Toby could add the sodium iodate, he dropped the test tube and shattered it. Then he began a new mixture. To a fresh beaker, he added baking soda, bleach, vinegar, blue food colouring and finally sulfur with sodium iodate. Toby observed. "It's fizzing."

"What causes the fizz?"

"The baking soda and vinegar. Now put it on the tripod. It should make purple smoke." A few moments later he added, "There's a lot of it in there so it won't, the mixture won't burn fast."

He heated the mixture. As the beaker stood over the flame, he added more sulfur. The mixture fizzed dramatically but there was no purple smoke.

This last experiment resembled its predecessor because the sodium iodate and sulfur were added to a pre-existing mega-mixture. It differed however because this new mega-mixture did not contain random chemicals. Rather it included vinegar and baking soda; Toby knew how these two chemicals reacted.

The effect of this reaction was surprising but not in a pleasant way. It was disappointing enough in the previous experiment when he produced only a little purple smoke. But this time he produced none at all.

Toby reacted to these disappointments like an engineer whose machinery seemed to malfunction. He decided to test his device in isolation. So he announced, "Now alone without

anything else, sodium iodate and sulfur."

He mixed the two chemicals and turned on the heat. "It's going to sort of explode into purple smoke. There it goes. There's a flame or spark inside. Okay stop."

So his machinery was tested and it proved in good working order. It reacted the way Toby predicted. Toby ended the test routinely. "I'm going to turn it upside down and pour it into the beaker. And all the purple smoke comes out."

Except the purple smoke did not come out routinely. First it flowed not smoothly like a liquid into the beaker but sloppily onto the table. Then suddenly Toby noticed, "It's staining the table. Everything around."

He immediately began to investigate the unexpected stain. He placed his hand in front of his test tube and poured. "It stained my hand yellow. I'll get a piece of paper." He did. "It's bending out sort of. Now all the smoke's gone. Quite a mess to clean up. I don't see why it did that."

Thus Toby's favourite chemicals confirmed their ability to produce unexpected effects. First Toby discovered that sulfur plus sodium iodate could produce purple smoke if handled correctly. Now he learned that the purple smoke would make a yellow stain.

Two classmates poked their heads in the door. "What are you doing?"

Toby answered, "I'm burning some sulfur. Come on in."

"Gee it stinks in here."

They came in. Toby added sodium iodate and sulfur to a fresh test tube and placed a cork in the top. "Watch out. The cork goes flying. I'm scared. But it goes flying."

Toby had previously made a cork hit the ceiling by heating a corked test tube. But that test tube had not contained sodium iodate and sulfur. Causing the cork to fly would be a new function for his purple smoke.

Toby turned on the heat. Soon the cork tumbled off the test tube unenthusiastically. The

anticipated explosion simply did not occur. However there was the expected chemical reaction which produced the purple smoke. "Watch this," Toby instructed his classmates. "I'm going to stain my hand. You see it'll stain everything yellow."

But it did not. As he poured the purple gas, his hand turned not yellow but purple, the same colour as the gas. For the second time in a row, the fourth time that day, his experiment had not worked the way he wanted.

Throughout this session, Toby increased more than simply the range of contexts in which he made his purple smoke. He in fact increased the generality of his criterion of variation. His first variations followed chemical criteria; he varied the specific chemicals in his mixture. His next criterion was physical; by corking his test tube, he altered the physical environment in which he produced his gas. His final criterion was social; he varied not only the objects in his environment but also the people.

During the third session, Toby repeated the experiments which had failed during the second week. First he heated sulfur and sodium iodate in the context of unfamiliar chemicals. The mixture included ferric oxide, phenolphthalein, sodium iodate and sulfur. When heated, it failed to produce purple gas.

Then Toby heated a mixture of bleach, vinegar, baking soda, sodium iodate and sulfur. Before turning on the bunsen burner, he placed a cork in the test tube. This experiment worked perfectly. The cork popped; there was purple smoke; and this gas turned yellow when he poured it onto his hand.

In a third experiment, Toby mixed sulfur and sodium iodate with green food colouring. He heated the mixture with a cork in the mouth of his test tube. First the cork popped. Then his mixture yielded a white smoke. While the mixture was heating, Toby added yellow food colouring. The gas changed from white to purple. Toby added more green food colouring and the gas switched back to white. Toby turned the test tube upside down over a beaker but nothing came out.

Toby devoted only a small part of the third session to his purple gas. He focused his attention primarily on two phenomena. He spent most of the hour distributing liquids in various proportions among different beakers. The resulting mixtures, he in turn mixed with each other. I noticed no interesting effects from any of these mixtures. Toby seemed trapped in an endless ritual pouring liquids back and forth.

His other pre-occupation was more interesting. At the beginning of the session, Toby informed me, "Last week I spilt bleach all over my shirt. When I got into class, it was a lighter colour."

Toby tried a few experiments with bleach. First he mixed bleach with baking soda. That experiment produced no noticeable result until he added vinegar which caused it to fizz.

Later some bleach accidentally spilt into a beaker of green water. The colour of the water faded. "It was green before I added the bleach. So I think maybe like before on my shirt, the bleach made the colour go away."

By the third session, Toby had begun regularly experimenting with the six chemicals that in the eighth session, he claimed were his favourites. These were vinegar and baking soda, sodium iodate and sulfur, his purple smoke, and bleach. They each were known to cause some specific interesting effect. Vinegar and baking soda produced fizzing; sodium iodate and sulfur made purple smoke; the purple smoke caused yellow stains; and bleach took away colour.

Toby's longest single sequence of related experiments occupied almost the entire hour of the fifth session. During this session, Toby formed a complex and meaningful sequence of actions from three of his former themes, transferring fluids from beaker to beaker, pouring gases and bleaching colours. This synthesis embodied a powerful physical insight: that his knowledge of how to pour liquids could be generalised to gases. This discovery was a particular case of the important principle that liquids and gases are both governed by the same laws of motion. Thus through interacting with the Chemicals World in his own preferred style, Toby gained access to the general

laws of nature which it embodies.

After avoiding the two chemicals during the fourth session, Toby prepared a mixture of sulfur and sodium iodate early in the fifth week.

"Is there anything else in there besides sodium iodate and sulfur?"

"No."

"Do you have any special purpose or not?"

"Yes." But he did not say what it was. "I know what's going to happen."

"So you just want to see what you know is going to happen?"

Toby ignored my question. He turned on the bunsen burner to heat his test tube. When his purple smoke appeared, he covered the test tube with a rag and turned the test tube upside down letting the gas spill into the rag.

A few minutes later, Toby cut some strips off a bar of soap. He placed the strips in a fresh test tube which he then started to heat. As a white gas rose from his preparation, Toby placed his hand over the test tube.

"Did it stain your hand?"

"No."

Without taking the test tube from the hat, Toby added yellow food colouring. "Smoke is coming again. I don't know but it smells like some spice."

An orange solid and a colourless liquid had appeared in the test tube. Gradually the solid was dissolving into the liquid. Toby turned off the bunsen burner and poured the solution into the small 150 ml beaker. As a gas began to rise from the beaker, Toby covered the container with his hand and shook it. Then he turned the beaker upside down and placed it on the table, preventing any more gas from escaping. On top of the upside down beaker, he placed a heavy jar.

Toby took the sulfur and added some to the test tube he had just been using. Then he reheated the test tube. Suddenly the mouth of the test tube burst into flames.

"Wow!" Toby turned off the bunsen burner and blew out the flaming test tube. "It smells like a skunk."

Toby removed the jar from on top of the overturned beaker. He lifted the beaker and placed the test tube directly beneath it. White gas rose from the test tube into the beaker. Then Toby flipped over the coupled instruments so that an upside down test tube was now directly above an upright beaker. He announced, "I want to trap some of my purple smoke."

Before this experiment, Toby had never trapped a gas in a container. He had poured gases out of beakers but never into them. Now he realised that like liquids, gases can be poured as well as spilt. They can be transferred from one container to another and held there. Furthermore, for the first time, Toby called the iodine gas "*my* purple smoke". His use of the possessive pronoun reflected his growing attachment so that he now saw himself as having a special relationship with the gas. The rest of Toby's behaviour confirmed the importance of his attachment. During the session, Toby generalised his knowledge of gas motion from his purple iodine gas to another white gas. Just as Jonathan used Mork as a reference point to compare with other television programs, so was Toby using the purple smoke as a reference point to compare with other gases.

To a fresh test tube, Toby added sodium iodate and sulfur. He placed the test tube over the bunsen burner and turned on heat. Then he increased the heat slightly. As soon as the purple smoke appeared, Toby removed the test tube from the flame and placed it directly beneath an upside down beaker, just as he had done with the white smoke. But his purple smoke was denser than air and it did not rise. So nothing happened.

Then Toby flipped over the two containers. When the beaker had contained the white smoke, this flipping caused the gas to rise into the air. But the purple flowed down into the beaker. When the beaker was full of purple gas, Toby turned it upside down and pressed it against the table. Next he placed the test tube, still upside down and still containing some purple smoke, also onto the table. A moment later, he lifted the test tube and poked a pen into it, still keeping the container

upside down. For a second, he placed the test tube on a piece of cardboard. Finally he carried it to the window and shook it, still upside down, until its contents had all departed.

Toby went back to the overturned beaker. He lifted the beaker to reveal a thick stain on the table. The core of the stain was purple but it was surrounded with increasingly fainter bands of yellow and orange.

"Toby, don't you find it interesting that where the beaker was, it stained purple but right around the outside, it stained yellow and orange?"

"That's because there's more smoke there."

Toby tried to wipe the stain with a paper towel but it did not budge. Then he poured a spoonful of bleach and placed the bleach on top of the stain. The stain quickly dissolved.

Toby had known since the third session that bleach removes colour. In the fourth session, he used that knowledge instrumentally to bleach the letters of his name into a blue paper towel. Now in the fifth session, he was using bleach for a pragmatic rather than a creative purpose. It was cleaning a stain that he could not otherwise remove.

Through a combination of chance and necessity, Toby was discovering connections among previously isolated items of knowledge. The first of these connections is that apparently unrelated procedures could be linked meaningfully together into a chain. This fact was not obvious at first. Toby saw no relationship between making purple smoke and bleaching stains. (For that matter, neither did I.) But there is a relationship. Making purple smoke is equivalent to producing a colour. Since bleach removes colour, this act of production serves to enable the later act of destruction.

Of course, this relationship was not obvious at first because of the physical state of the purple smoke. Heating sodium iodate and sulfur causes a purple gas. Being a gas makes it difficult to bleach. You cannot easily pour bleach on a gas. Its bleachability becomes apparent only when you can trap the gas in a small confined space.

But most people would not think naturally of trapping a gas in a small space. Jonathan and

Leonardo never thought of it, and before this session neither did Toby. For children, and I suspect for most adults, trapping a gas is a complex procedure. It requires you first to direct the movement of this gas. Next it requires you to arrest this movement.

From his previous experiments, Toby had discovered the component procedures necessary for trapping a gas. Like most people, Toby had expert knowledge of how to trap non-gaseous fluids. He had spent most of one session trapping various liquids in assorted containers. Furthermore, unlike most people, Toby knew something about directing the flow of a gas. By this point, he had successfully poured gas onto pre-selected targets.

Toby's new insight was to pour his gas into a container. At first, this may hardly seem different from pouring it onto a piece of paper. And intrinsically, the procedures themselves are no different. The difference is purely, yet importantly, functional. A piece of paper arrests the movement of a gas only in one direction, down. On the other hand, a beaker arrests its movement in any direction, except directly up. Furthermore, a beaker placed upside down on a table quickly forces the gas to a state of equilibrium where it does not move at all.

The effect of a container on the movement of a gas is not surprising. Containers have the same effect on the movement of liquids; that is why we drink from cups instead of plates. Most people however do not notice the similarity between gases and liquids. Unlike most people, Toby did notice the similarity.

This discovery led him to pour first the white smoke and later his purple smoke back and forth between containers. It enabled him to localise his purple smoke in a fixed place. And it revealed the connection between sodium iodate and sulfur, on the one hand, which make purple smoke, and bleach, on the other, which consumes it.

Toby first discovered the similarity between two favourite procedures, pouring smoke and pouring liquids. He could then find the connection between two other favourite procedures, creating a coloured smoke, and bleaching away colour. Finally he was able to connect all these themes into a

chain since they could all be applied to the same attachment object, his purple smoke.

[We should also consider the aesthetics of this connection. Making and bleaching purple smoke are not related arbitrarily; rather they compliment each other like yin and yang. In effect, Toby discovered that the creation of colour can be reversed, that bleaching provides the mirror image of heating sodium iodate and sulfur. This complementarity between creation and destruction is often considered an especially moving pattern. In fact many people revere it as a religious symbol.]

This last session was held on the eleventh of June, 1979. For the following three months, Toby was away on summer holidays; so the study had to be suspended. Thus Toby's last discovery before the holiday was the complimentary relationship between making and bleaching purple smoke. Our next session was held at the beginning of the following school year, on September 17.

Toby's first act, on entering the research room, was to mix sodium iodate and sulfur in a test tube. As he began to heat the mixture, a yellow gas appeared. Then the gas turned pale purple. Within a few seconds, the purple became deep and rich. "It's purple now. Purple smoke is coming out."

Within a few moments, Toby placed a funnel into the mouth of the test tube and through the funnel poured some bleach. Immediately, the purple smoke turned into a colourless steam. Toby observed, "It just goes away 'cause of the bleach."

Simply and cleanly, Toby was able to demonstrate a phenomenon which had taken him most of the previous session to discover. He no longer needed the intermediate steps of pouring the gas and trapping it in the beaker. Their function had been purely intellectual. They had served a bridge between his purple smoke, which was a gas, and bleach, which he had previously used only on liquids and solids. Since their function was intellectual rather than physical, he could prune them away once he saw the connection between heating and bleaching.

Toby made one more discovery. During the second session,

Toby had tried to impress his classmates by pouring purple smoke.

At that time, his efforts had seemed in vain. Not only had the purple gas failed to stain his hand

yellow as he predicted, but his classmates failed even to express some appreciation for his producing the purple gas. Toby's last discovery was that his purple smoke could indeed serve as a social resource as well as an intellectual one. When staged effectively, his purple smoke could attract considerable attention.

During the seventh session, Toby showed his chemicals to a group of classmates. This time, many of his peers seemed to admire the 'sulfur plus sodium iodate' experiment. The show must therefore be considered a modest but real success. Ironically most of the children paid attention to issues of little consequence to Toby. They chattered about the supposed danger of Toby's experiments. And they complained about the chemicals' stench.

Toby eventually learned that his purple gas could bring him status but not because of the colour, or the pouring, or the bleaching. Its social value came from its smell.

During the last session, Toby told me, "Last week I smelled up the whole school, Everyone I knew smelled it."

"Did they know that you did it?"

"No." Then he added grinning smugly, "I told them." He continued, "Even in the cafeteria. In the cafeteria, they smelled it."

A few minutes later, he announced, "Now we smell up the whole school."

"How are you going to do that?"

"Easy." He started adding sulfur and sodium iodate to a clean test tube.

"Are you sure you want to smell up the whole school?"

"Right."

"Why? You don't like the school?"

"I just want to see if I can this week."

Toby heated his mixture. When the purple smoke appeared, he carried the test tube around the room, pouring gas into the air. When only a little gas remained in the test tube, he returned the

bunsen burner and reheated the mixture. This made more purple smoke which Toby could dump into the air. After a few minutes, Toby was choking on the stinking air.

Toby continued to make new mixtures. One consisted mainly of bleach, with an assortment of random chemicals added. Toby heated the beaker but within a few seconds fled from the chemicals to a distant corner of the room. From the distance, he remarked, "That's what the purpose is."

"To smell up the school?"

"Yes."

"Did you know it would smell like that?"

"I didn't know what it would smell like."

He made another mixture of water, bleach, red food colouring, vinegar, dirt, salt and phenolphthalein. "It might be liquid alcohol. It smells like yeast to me. Maybe it is yeast."

He heated the mixture and it bubbled up to form a foam in the shape of an ice cream cone. "It looks like yeast sort of." A few moments later, he added, "All I know is it's going to make a mess."

"Speaking of messes, I think you better start cleaning up."

"Already!"

Toby had evidently been so involved with his work that he had not noticed the end of the session.

I would have been willing to work longer with Toby in the Chemicals World. But when I asked him if he wanted to continue, he answered that he did not know. Comments such as Toby's remonstrative "already" suggested to me that he did not want to stop. I felt though that the time had ended when I should infer his wishes. If he expressed no explicit preference, I would begin the work with *Mork and Mindy*.

So Toby ended his exploration of the Chemicals World.

5. Equilibration: A Framework for Representing Learning

5.1 Learning as a Developmental Process

It is common in Psychology to emphasize the differences between behavioural and cognitive theories of learning, to observe that the former picture learning as a process of conditioning, in which behavioural changes serve as a means to earn resources from the environment, while the latter see learning as an intellectual process, in which changes in knowledge serve as a means to find the solutions to problems. In this chapter, I will develop an alternative to both familiar types of theories by analysing a kind of learning that cannot be reduced to either conditioning or problem solving. My model will be an elaboration of Piaget's theory of equilibration, a theory which underscores the interaction between thinking and behaviour rather than their autonomy from one another.

An assumption shared by both behavioural and cognitive theories is that learning is an instrumental process. There is of course considerable disagreement about the precise end which learning serves, with behaviourists emphasising the economic rewards of learning such as food and other biologically necessary commodities, as well as such emotional rewards as approval, and cognitive psychologists placing more importance on consciously accepted goals, such as the goal of solving a mathematical problem. Nevertheless almost all research into learning studies people, or animals, with a clearly definable motive for adapting. In the cases of Jonathan and Toby, it is possible, of course, to postulate ends to which their learning was directed. One could imagine that I was giving them subtle reinforcement for elaborating certain of their ideas or that they themselves had identified problems which they wanted to solve. But the point of my analysis is that we have no need to postulate any ulterior motives, because we can explain their learning as a natural consequence of their spontaneous thoughts and actions. By picturing learning as an innate ability, as characteristic of human beings as the ability to use tools or to form relationships, I am identifying myself less with the mainstream of American Psycholgoy and more with such educational theorists as

Rousseau, Dewey, Montessori and most recently Seymour Papert.

In providing an alternative to the instrumental view of learning, my theory fills an undeniable gap in Developmental Psychology. Piaget is only the most famous of many psychologists, including Lewin, Werner and Vygotsky, to picture psychological developmental as functionally autonomous process, analogous to the organic growth of plants and animals. A major problem, however, for all these theorists, has been the difficulty in formulating a rigorous explanation of how such organic development can emerge. Given the lack of any mechanisms in Psychology for generative non-goal directed processes, any theory represents a significant advance, even in the absence of definite experimental support.

My theory was derived from an inductive analysis of the experiences of Jonathan and Toby, in which I formulated detailed descriptions of what both boys learned and of the process which produced their learning. At a later stage, I constructed a theoretical mechanism, the mechanism of equilibration, consistent with the behavioural changes that I observed. In this chapter, I will present the steps through which my analysis of Jonathan and Toby yielded my final theory. I must begin however with an overview of both boys' experiences in the two research micro-worlds.

5.2 What Jonathan and Toby Learned

It is useful to view the events in both the Chemical World and the *Mork and Mindy* World as resulting from the interaction of two kinds of causes, one being the specific content of the individual micro-worlds and the other being the general laws of both nature and society. The importance of both these factors is easy to demonstrate. Clearly if the specific chemicals in the Chemicals World had been different, then Toby could not have become interested in making purple smoke. Similarly if the specific episodes and characters in *Mork and Mindy* had been different, then Jonathan's analysis of the basketball joke and the theft incident would not have taken place.

Nevertheless the specific content of the two micro-worlds was not the only cause of the events which I reported; the underlying general laws were also important. If the laws of chemistry had been different, then purple smoke would not have appeared when Toby heated sodium iodate and sulfur. And if the aesthetics of story telling were different, then purple smoke would not have appeared when Toby heated sodium iodate and sulfur. And if the aesthetics of story telling were different, then Jonathan's theme of fictional realism would not have proven useful in analyzing Mork's behaviour.

Corresponding to the distinction between these two kinds of causes, we can also distinguish between two kinds of knowledge which micro-worlds teach, particular facts and powerful ideas. Particular facts are facts specifically about the micro-world which lack the generality to be usable in other settings. Powerful ideas, on the other hand, are ideas about nature and society exemplified by but not limited to the micro-world.

Obviously Jonathan and Toby learned a great many particular facts during the research. They learned a little about me: my name and my appearance, my working habits, my affiliation with Harvard, my interest in television, chemistry and children. They learned also about the two micro-worlds: they learned the names of various chemicals as well as some of they physical and chemical properties, the identities of the *Mork and Mindy* characters as well as their styles of interacting with each other.

Such particular facts however are not the learning which does or should primarily interest psychologists and educators. If education has value, the knowledge it teaches must be applicable outside the classroom. The important learning for both Jonathan and Toby was not the particular facts they learned but rather the powerful ideas.

Clearly Jonathan and Toby both acquired some powerful ideas. Consider Jonathan's concept of fictional realism. The most basic property of a fictional work is that it differ somehow from real life; otherwise the work would be history instead of fiction. But fiction can never be totally

unrelated to reality. The greatness of a literary work depends on the author's ability to clarify a fundamental fact or problem of human life by selecting and modifying the less important details. You begin to appreciate literature when you notice the underlying similarity between fiction and reality. Thus Jonathan hit on a basic idea which allows him to achieve genuine literacy.

Toby's intellectual style differed from Jonathan's by focusing his attention on a broader range of themes, none of which were pursued as deeply as Jonathan's concept of fictional realism. Among Toby's many themes, there were some quite powerful physical, chemical and social ideas. The most obvious powerful physical idea was his discovery that gases have mechanical properties similar to liquids. Next Toby's discovery that gases, solids and liquids react chemically is notable, especially considering that Jonathan, although three years older than Toby, believed that chemical reactions were always between liquids. Finally, the study witnessed a change in Toby's knowledge about impressing his peers. Early in the study, he tried to show off the chemical reactions which had attracted his interest, making hardly an impression on his classmates. By the end of the research, he learned that power and not attractiveness was what really impressed other children; he managed to win the admiration of his classmates by producing a vile and inescapable smell.

For both Jonathan and Toby, these experiences at the research played an important role in their acquisition of these powerful ideas. We can begin to articulate this role by reconsidering a comment by Jonathan about the television series *Battlestar Galactica*. "When they can go over and pull a spaceship toward them using a tractor beam, and blow it up using a supersonic laser, and get out of there going 5 million lightyears, I don't know. It doesn't sound realistic but it is realistic to the show. It's realistic on *Battlestar Galactica* where they can blow up another spaceship using a laser."

That Jonathan made this comment near the end of the research is not surprising. There is no reason of course why this comment could not have been made before the research nor why Jonathan's experience with *Mork and Mindy* made this observation inevitable. In other words, the research was neither a necessary nor a sufficient condition for Jonathan's statement. Nevertheless,

Jonathan's analysis of *Mork and Mindy* affected the likelihood of such a statement. Before the research, there was no reason to expect such an idea from Jonathan. After our many discussions about realism, this comment appeared completely in character for Jonathan. It seemed an obvious extension of his earlier thinking.

The study witnessed a gradual and continuous proliferation of Jonathan's realism theme. It originated at one small point in the *Mork and Mindy* world: Jonathan wondered if realistically Mork would dance at a basketball game during the *Star Spangled Banner*. Then it spread throughout the entire conceptual world and beyond. First Jonathan assessed the realism of several other jokes. Next he applied the concept to *Mork and Mindy* characters other than Mork. Later he evaluated larger units in terms of their realism: entire episodes, whole television series and works from other fictional media. For Jonathan to consider the realism of a television series fits perfectly into this pattern. It is especially logical that he chose a second science fiction series.

There was the same continuous proliferation in Toby's themes. Consider the experiment when Toby mixed liquid bleach with purple iodine gas to produce a colourless liquid. Never before had Toby mixed a liquid and a gas. Nevertheless this particular experiment seemed an obvious extension of his earlier sequence of experiments. Through the previous five sessions, experimenting with both bleach and iodine gas had become themes for Toby. He noticed the bleach during the session when he accidentally spilt some on his shirt, causing the colour to fade. He discovered the iodine gas during the first week; when he heated a mixture of sodium iodate, sulfur and table salt. These two themes became combined into a single experiment during the fifth session; after pouring his purple smoke back and forth among his test tubes and beakers, Toby finally dumped it onto the table causing a deep purple stain which he subsequently removed with bleach. Toby bleached his purple gas in the session just after he had bleached the purple stain.

The significance of the research in both boys' learning is that it let them notice and then use certain powerful ideas. Through systematic use, these ideas became generalized throughout the

conceptual worlds derived from the research micro-worlds, and beyond.

5.3 Control

One current obstacle to formulating psychological theories of learning is analogous to a problem faced in the seventeenth century in formulating physical theories of motion. Although physicists at the time knew all the necessary facts, they could not discover classical mechanics because they lacked a language for describing physical interactions. Newton was able to formulate his laws of motion in part because his discovery of calculus gave him the required formal language. Similarly, I believe, psychologists have had trouble formulating theories of learning not primarily because of a shortage of facts but rather because we have lacked a formal language for describing the interaction between mind and behaviour. We have been unable to articulate in rigorous terms either how knowledge changes as a result of experience or how behaviour changes as a result of thought. One contribution that Artificial Intelligence has made to Psychology has been the development of a formal language to describe these interactions. A fundamental concept in this language useful in understanding the growth of Jonathan's and Toby's knowledge is the concept of control.

In analyzing Jonathan's discovery of fictional realism and Toby's discovery of purple smoke, I will concentrate on questions of control, their exerting control over their own behaviour as well as their accepting control from the environment. But before considering the function of control in children's learning, I want to describe a simpler and better understood case of control, the control of machines.

Technology provides a useful micro-world for discussing the issue of control both because formal theories exist to explain how machines are controlled and because control over our environment is the justification for humanity retaining technology. As an example of a machine, consider a heating system, a machine which produces heat from the energy stored in wood, sunlight

or fossil fuels in order to maintain the temperature of a private home. The job of heating a home can be performed my many kinds of systems, some as traditional as a fireplace and others as modern as a solar collector. The more traditional systems seem most attractive when we want to involve ourselves directly in the process of providing heat such as when we sit and watch a fire, adding fresh wood whenever the flame subsides. The modern systems are more attractive when we want to let the heating system control itself. Most homes include a special machine, a thermostat, whose function is exclusively to exert control over the heating system.

The behaviour of a thermostat can be understood most easily by distinguishing two of its parts, a thermometer which measures the temperature in the home and a switch which turns the heating system off and on. These parts are connected so that the heating system remains on only as long as the measured temperature stays below a critical value. The flow chart shown in figure 6.1 graphically illustrates the structure of a thermostat. The thermometer is represented as a comparator which determines whether the temperature is below the critical value or not. The two boxes represent the two possible reactions to the output of the comparator, either to cause the heating system to be on or to cause it to be off.

FIGURE 5.1

A Flow Chart Representation
Of A Thermostat's Control Structure
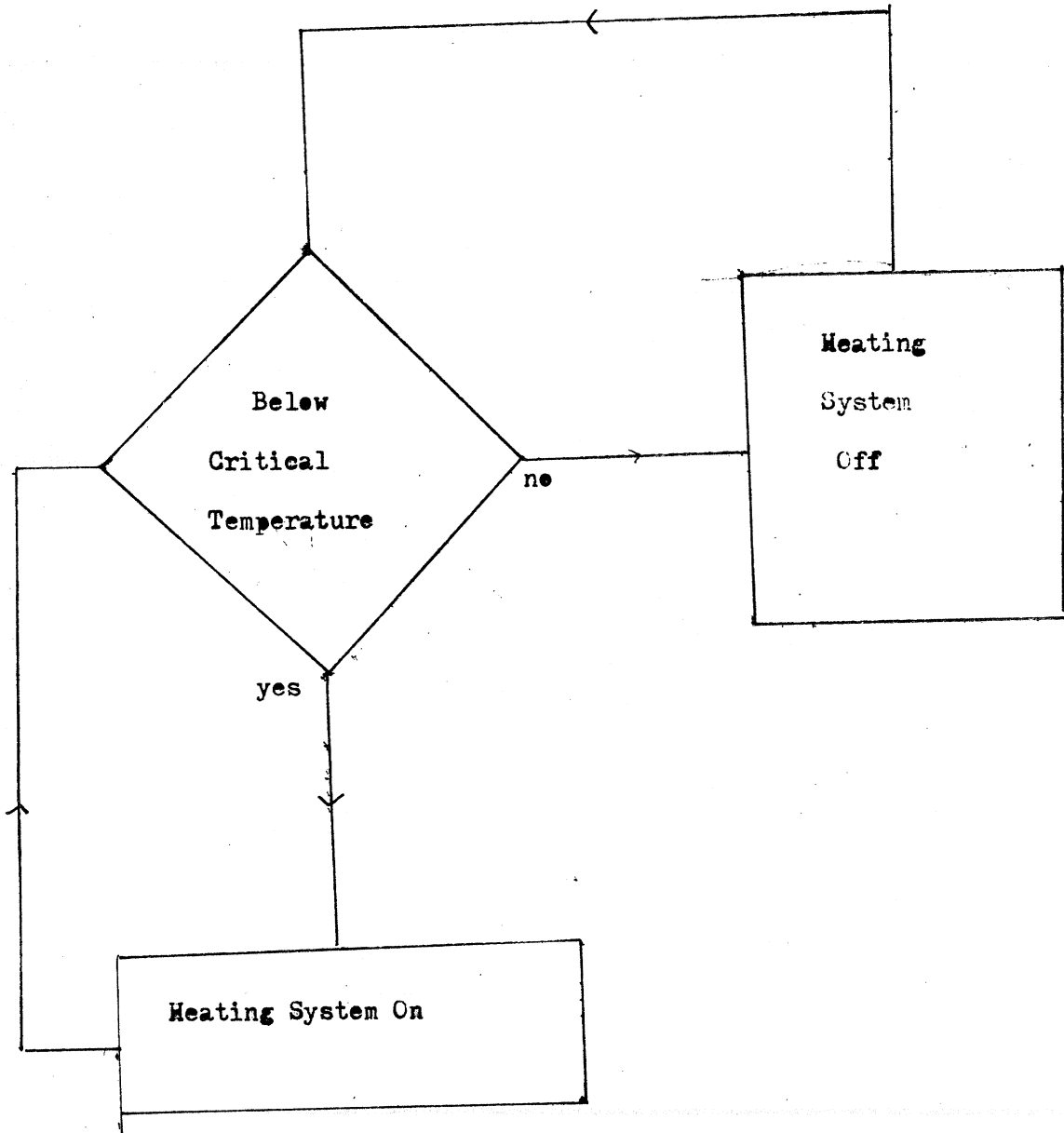
The thermostat is an example of the earliest kind of control structure to be studied by engineers, the negative feedback system, so called because it constantly negates the effect of its own labour. We perceive this process of negation when we observe a thermostat turn off the heating system as soon as our home has reached a comfortable temperature, thereby letting the temperature drop to a point where the thermostat will turn the heating system back on. Negative feedback systems serve to keep some variable near a desired value just as the thermostat keeps our home near the desired temperature. Therefore they are most useful for dampening the effect of physical variables such as temperature which naturally fluctuate so greatly that they jeopardize human comfort and health.

Since the discovery of negative feedback, engineers have become interested less in machines like thermostats which prevent change and more in ones like computers which produce it. Computers differ from thermostats because they contain many levels of control. The lowest level control structures resemble thermostats in that they control the value of a physical variable, the presence or absence of an electric current in one of the computer's registers. But unlike a thermostat, it is not the physical properties of the register which primarily interest the engineer but rather the very fact that it represents a variable. This fact makes it possible to build higher level control structures which manipulate the register in the same way as arithmetic and logical functions manipulate variables. By embedding these functions in even higher level control structures, it becomes possible for a machine to perform complicated data processing.

The flow chart show in figure 5.2 represents the top level of control of a program written in the early 1960's known as the general problem solver or GPS (Newell and Simon, 1963). GPS can be used to solve problems, like the ones found in courses of propositional logic, where a current state, such as a list of premises, needs to be transformed into a goal state, such as a logical conclusion, using a specified set of operations, such as rules of logical inference. Like the thermostat, GPS includes a comparator which looks for a difference between its current state and its goal state. If it finds a

difference, GPS consults a table which lists the operations applicable given the existing difference and then applies one of those operations, GPS cycles over and over again through this loop until it can detect no difference between the current state and the goal state, at which point the program stops.

- 96 -

FIGURE 5.2

A Flow Chart Representation of GPS
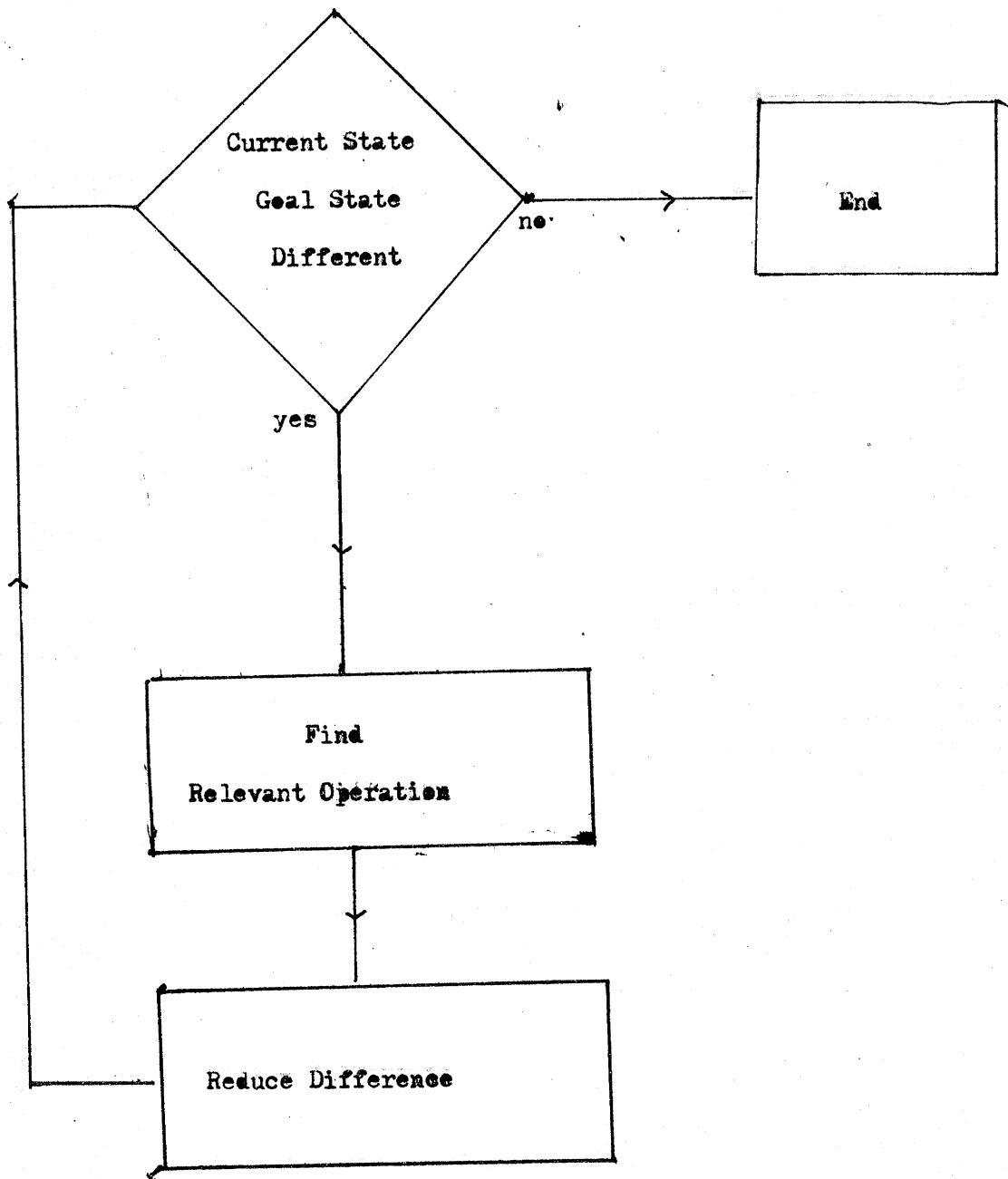
Herbert Simon (1969) has pointed out that biological and psychological systems will usually have the same structure as manmade systems when they perform the same function subject to the same environmental constraints. A good example of the analogy between biology and technology is the structural similarity between the bird and the aeroplane. Since bird flight and aeroplane flight are both subject to the same physical constraints, the bird wing must have roughly the same size and shape, relative to body weight, as the aeroplane wing. Similarly there are psychological structures which control human behaviour analogous to structures such as negative feedback and GPS which control machine behaviour. It is known that many physical parameters of the human body such as calory intake, water, salt and protein levels and body temperature are all regulated by negative feedback structures in the same way that room temperature is regulated by a thermostat. More recently, cognitive psychologists such as Newell and Simon (1970) have claimed that structures which control computer problem solving are the same as the ones which control human problem solving. As Simon has argued, the reason for this analogy between living and manmade systems is the need to adapt. Only because both are subject to the same environmental constraints do we expect any structural similarity.

During the present study, the behaviour of neither Jonathan nor Toby displayed the characteristic symptoms of either negative feedback or GPS. Unlike negative feedback systems, they did not regulate the values of specific physical parameters; and unlike GPS, they spent little time solving problems by transforming a current state into a goal state. Neither however need we conclude that their behaviour was controlled by a structure unrelated to negative feedback and GPS simply because this structure was not identical to either of these two familiar mechanisms. If we ignore differences of detail, we can recognize a fundamental similarity between negative feedback and GPS. The overall organization of both control structures is iterative: each iteration begins with a comparison between the existing state of the world and some reference state; if these two states are equivalent, the system rests; otherwise, it produces some transformation designed to bring these two

states closer together. It is this general level of description, I believe, which reveals the relevance of machine behaviour to the control of Jonathan's and Toby's learning. Although the specific comparisons and transformations were different, the constant alternation between these two types of operations were as characteristic of Jonathan and Toby as of negative feedback and GPS.

Consider the session when Jonathan analyzed Mork's dancing to the American national anthem. Jonathan first compared his belief that Mork's behaviour was realistic with the details of the dancing episode when he asserted that a spaceman like Mork would think under the circumstances that he was supposed to dance. The result of that comparison served to cast doubt on this initial assessment; Jonathan could see no clear difference between a human being from another culture, who would not dance, and a spaceman from another culture, such as Mork. Immediately after this exchange, Jonathan began to transform his opinion of Mork, a transformation which soon became apparent when he described Mork as "exaggerated." Then he compared his new opinion of Mork with the dancing incident deciding that it was almost believable. Before the end of that session, he revised again is opinion of Mork concluding that a spaceman would follow what everyone is doing exactly if he heard the *Star Spangled Banner*. On the basis of this judgment, Jonathan stated that the incident had been unrealistic.

It is possible to imagine a simple structure which could provide the top-level of control for Jonathan's analysis of Mork's dancing. The comparator within this structure would test whether his current theory fits the facts. It it did not, a specific transformation would be introduced into the theory and it would be tested again. This process of comparison and transformation would continue over and over again until the theory and the facts conformed to each other, at which point the process would stop, at least for the time being.

A virtue of this simple structure, its generality, can be demonstrated by considering the behaviour of Toby at the time he discovered purple smoke. As you will recall, he stumbled on the purple smoke accidentally when he heated a mixture of three random chemicals, sulfur, sodium

iodate and salt. He believed at first that the colourfulness of one of his chemicals caused the colourfulness of the smoke. He tested this theory, proving it wrong, when he heated sulfur, the only one of his three chemicals having a colour other than white. One transformation of this theory was that purpleness and not colourfulness produced purple smoke; this theory Toby proved wrong when he heated his one purple chemical, cuprous oxide. Another transformation was that a combination of chemicals, sulfur plus sodium iodate, was responsible for the reaction. This last theory seemed right to Toby because heating those two chemicals caused his smoke to appear.

In the early part of the research, the transformation phase of the comparison-transformation cycle consisted in a transformation of theory. For Jonathan, these transformations caused a change in his theory of Mork's realism, for Toby they changed his theory of how purple smoke is made. This first stage of learning may be called the *discovery stage* because it served to teach principles governing the behaviour of the research micro-worlds. In contrast, both boys tended to retain their theories unchanged during the final part of the study. Their later transformations served to alter the context in which they applied their theories rather than the theories themselves. This second stage of learning may be called the *proliferation stage.*

The partial analogy between Jonathan and Toby on the one hand and negative feedback and GPS on the other supports Simon's explanation of why psychological and technology systems will have the same structure. Like negative feedback and GPS, the function of Jonathan's and Toby's behaviour may be described as problem solving. Jonathan seemed to be solving the problem of explaining why Mork danced at a basketball game; Toby seemed to be discovering a method of synthesizing purple smoke. As with manmade problem-solving systems, it was useful for both boys continually to monitor the state of their solutions in order to recognize when the problem was solved. Like GPS, Jonathan's and Toby's monitoring served not only to identify solutions but also to clarify the current problem needing to be solved. The most efficient method to coordinate innovation and adaptation, for a person as well as for a machine, is to alternate systematically between transforming

one's solution and comparing it with reality.

The important difference between Jonathan and Toby and the two machines is that Jonathan and Toby were in the process of learning whereas the machines were not. Negative feedback systems and GPS both live in a micro-world of pre-established harmony. Both are special-purpose devices used only to serve the function which they were built to serve, and incapable of learning new skills (unless one consider a computer program to be learning new skills when a programmer changes its code.) On the other hand, human beings are general-purpose systems capable not only of functioning in familiar micro-worlds but also of adapting to new ones.

The ability to learn makes problem solving an intrinsically more complex process for a human being than for GPS (or for a negative feedback system). For GPS, to solve a problem requires only that it keep changing the problem's current state, gradually bringing it closer to the goal state, using the tried-and-true operations stored in the system's data base. But for a human being, functioning in an unfamiliar micro-world, problems inevitably arise admitting of no tired-and-true solution. The experiences of Jonathan and Toby prove that such problems can be solved; however doing so demands not merely the application of familiar operations but also the discovery of new ones.

Therefore the human mind requires levels of control higher than GPS just as GPS requires levels of control higher than the thermostat. Like the thermostat and GPS, the human mind must have a low level of physical control which operates directly on the physical world. And like GPS, it needs an intermediate level of computational control, useful in the solution of routine intellectual problems. But in addition, human intelligence requires a third higher level of adaptational control which can modify existing intellectual structures to serve new demands. This highest level of control allows people to solve unanticipated problems in unexpected micro-worlds. It is this capacity for self-modification that allows human beings not only to exert control over familiar micro-worlds, a talent we share with both thermostats and GPS, but also to gain control over new ones.

That discovery phase followed by a proliferation phase leads to an increase in control is a familiar idea, although not within the psychological community where the issue of gaining control has rarely been addressed, but rather among historians of science. Even scholars as fundamentally in disagreement as Karl Popper and Thomas Kuhn recognize that scientific research always includes two phases. The first phase, which Popper calls "conjecture" and Kuhn calls "revolutionary science," is a time when new ideas. are discovered; the second, which Popper calls "refutation" and Kuhn calls "normal science", consists in applying these ideas to new contexts (Popper, 1962; Kuhn, 1962).

From a functional point of view, there are definite reasons why learning should be organized into a discovery phase and a proliferation phase. A useful property of Jonathan's and Toby's learning process was that it generalized successful ideas while keeping bugs local. By the end of the study, Jonathan's realism theme and Toby's purple smoke theme had been applied to a large number of contexts. In fact, it was this ability to be generalized that made both themes powerful. But the themes they generalized were not the ones present at the beginning of the study. Early in the research, Jonathan debugged his conception of Mork as weird, by distinguishing genuine weirdness first from fictional realism and then from exaggeration. Similarly, Toby debugged his theory that colourful powders make colourful smoke by discovering that the chemicals themselves and not their hue produce the colourfulness of the smoke. This practice of testing and transforming their earliest ideas immediately not only led them to the discovery of better ideas but also kept them from generalizing their poorest ones.

The importance in Jonathan's and Toby's learning of both discovery and proliferation is surprising given that the distinction between these two phases does not occupy a prominent position in psychological theory. One possible reason is that psychologists interested in Cognitive Science, the ones most likely to be sensitive to the issue of control, have devoted little attention to the study of learning. However this statement presupposes that computational ideas represent a fundamental change in psychological thinking, a supposition I consider unwarranted. Although Cognitive Science

has introduced a new language for describing processes such as control, pre-computational precursors of this language have traditionally been part of psychological discourse. In fact, one of the most familiar distinctions within the psychological community differentiates "mentalists" who see behaviour as controlled by internal mental processes from "environmentalists" who see external rewards and pressures as the source of behavioural control. Discovery and proliferation have been neglected, in my opinion, not because psychologists have ignored the issue of control but rather because both the mentalist and environmentalist points of view tend to obscure the control processes most important in learning.

GPS is a good example of a mentalist theory of control because it makes apparent both the strengths and weaknesses of that point of view. Like the theories of motivation characteristic of pre-computational mentalist psychology, GPS is intended to explain how high level goals organize ongoing behaviour. The strength of GPS, interpreted as psychological theory, is that it can and does invoke individual operations under conditions when they serve the goals of the system, or the person, and only under those conditions. But the weakness of GPS is also one shared by older mentalist theories, namely that it cannot adapt to surprises from the environment. One reason why Toby learned to make purple smoke is that he became interested in making it once he stumbled upon it by accident. Similarly one reason why Jonathan learned to identify realistic television programs is because the concept of realism grabbed his interest after an accidental encounter. But GPS can acquire new goals no more than traditional theories of motivation explain the acquisition of new motives. Its impermiability to environmental influence makes it incapable of making real discoveries.

Environmentalist theories of control have virtually the opposite strengths and weaknesses to the mentalist theories. Environmentalist theories, such as those which picture learning as conditioning, explain how surprises can cause a system to alter its behaviour. The weakness however of those theories is their failure to explain how an intelligent system, such as a human being, knows the right alteration to select. Neither Jonathan nor Toby changed their theories or their behaviour

randomly. Rather every variation was directed a correcting a specific bug that experimentation, criticism from me or their own self-criticism had revealed. Since environmental theories picture alteration as either a random or reflexive process, they cannot explain why people so often discover the precise variation that will solve the problem in need of debugging.

Discovery cannot be explained by purely mentalist or purely environmentalist theories because it is not the result of exclusively mental or exclusively environmental processes but rather of their interaction. Let us reconsider Jonathan's analysis of Mork's dancing. Originally Jonathan and I began discussing the incident because of a pre-existing interest of Jonathan's; next my asking whether a Chinese would dance in Mork's position served to undermine Jonathan's confidence that Mork's behaviour really had been realistic; finally Jonathan's discovery of "exaggeration" led him to reconstruct his theory of the incident. In the course of this one discussion, the control of Jonathan's behaviour passed from his own interest, to my criticism to his own reconstruction.

This variation between mental and environmental control was characteristic not only of this particular discussion but of every time Jonathan or Toby made proliferated discoveries. Consider the incident when Toby first discovered his purple smoke. Control passed from an interest of Toby's in trying new chemicals, to the unexpected appearance of purple smoke, to Toby's theory that the purple resulted from the colourfulness of the reagents, to the failed experiment when heated sulfur did not produce purple smoke. The locus of control followed this same pattern of alternation when pre-existing themes proliferated. When Toby learned about pouring gases, control passed from the white gas which appeared to rise, to Toby's existing attachment to purple smoke, to his failure to make purple smoke rise, to the insight that he could make purple smoke pour downward.

The significant feature of all these examples is the fortuitous role played by good timing. The reactions either of Jonathan and Toby or of their environments contributed to their learning only because they happened at the right time. For Jonathan, the importance of "exaggeration" was not an intrinsic property of the concept but rather the result of the context when it popped into his mind.

Similarly, for Toby, the importance of the purple smoke's failure to rise came not from the phenomenon itself but from Toby's pre-existing expectation. Both boys were able to sustain their learning because of the high compatibility between the thoughts in their minds and the events in the micro-worlds. Their minds kept producing ideas that made novel use of their environment and the micro-worlds kept producing phenomena that inspired their minds.

This compatibility between their minds and their environments illustrates the essential reason why interactive control is theoretically important. Virtually all existing theories of control, both in Psychology and in Artificial Intelligence, ignore phenomena, such as discovery and proliferation, where mental and environmental structures enter into sustained interaction. As a consequence, the known mental control structures lack the compatibility to the know environmental control processes that could yield the intellectually productive interactions experienced by Jonathan and Toby. It follows that we require a theory of control fundamentally different from the familiar ones. It would not be sufficient to describe interactive control structures to relate familiar mental control structures to familiar environmental control processes. We need to discover not only interactive control structures but also mental and environmental control mechanisms sufficiently compatible with each other to enter into productive interactions.

I can clarify the difference between synthesizing established theories of control and developing a new one by contrasting two famous attempts to explain interactive control: the theory of production systems proposed by Newell and Simon (1972) and the theory of equilibration advanced by Jean Piaget (1956, 1975). Of the two, Newell and Simon's theory is generally regarded more favourably by psychologists. Its authors have demonstrated its formal adequacy by implementing production systems as computer programs; and they have demonstrated its explanatory power by using it to account for a large number of discoveries from Cognitive Psychology. In contrast, Piaget's theory has been poorly received. However, as I will now argue, Piaget's theory has one important advantage for present purposes over Newell and Simon's, namely

that it can help to explain discovery and proliferation.

As we have already noted, a basic limitation of GPS is its insensitivity to environmental control. While it could solve problems once activated, it could not activate itself automatically in response to salient environmental states. The theory of production systems was a direct attempt to solve this problem. By combining the capacity of stimulus-response systems to react to the environment with the ability of GPS to solve problems, Newell and Simon designed an information processing system intended to explain all human problem solving.

The name of Newell and Simon's theory comes from the structure which, in their opinion, controls human problem solving, the production. This structure is composed of two lists, a "left-side" consisting of situations which should activate the production and a "right-side" asserting the actions performed in these situations. This pairing of activation conditions with output activity makes the production the prototype of a stimulus-response system. The difference between productions and older stimulus-response theories is that the actions listed on the right-side of a production can be arbitrarily complex due to their hierarchical structure. Unlike simple commands to operate directly on the environment, a production can solve difficult problems by invoking sub-procedures just like GPS.

Unlike behaviourist theories of stimulus and response, Newell and Simon acknowledge the influence of internal mental control structures. Nevertheless they remain faithful to the spirit of stimulus-response Psychology in that they subordinate mental control to higher level environmental control. In assigning priority to environmental control, Newell and Simon serve as a sharp contrast to Piaget. Like Newell and Simon, Piaget acknowledged the influence of both mental and environmental control structures. But in contrast to them, he attributed the highest level of control to the mental process which he called "equilibration."

The simplest case of equilibration, and the only one relevant to the present argument, represents the relationship between two lower level control processes which Piaget called

"assimilation" and "accommodation." Assimilation and accommodation are both similar in that they serve to vary an ongoing pattern of behaviour, the difference being in the means they use. Assimilation varies the environmental context so that the behaviour pattern must adapt to new external constraints. An infant demonstrates his ability to assimilate when he adapts his present skill at grasping small objects, like key-chains, to the need to grasp large objects, like beachballs, by introducing minimal changes in his pre-existing grasping technique. On the other hand, accommodation changes a behaviour pattern by varying the underlying control structure. Piaget's son Laurent demonstrated this ability when he began systematically hitting a mobile with the stick he was holding, after one accidental collision between the mobile and the stick (Piaget, 1935).

The distinction between the behavioural processes, proliferation and discovery is analogous to the difference between the control processes, assimilation and accommodation. My example of proliferation, Toby's pouring of the purple smoke, would be considered a case of accommodation by Piaget. He would observe that Toby was assimilating his pre-existing ability to make purple smoke to a new context, namely the context of gas-pouring experiments. Similarly, my examples of discovery would seem to Piaget as instances of accomodation. For example, he would see the accidental appearance of purple smoke as analogous to the collision between Laurent's stick and the mobile so that Toby's repeated synthesis of his new compound would be like Laurent's attempts to re-enact his discovery.

This analogy provides the first hint of how Piaget's theory is useful in explaining the experiences of Jonathan and Toby. According to Piaget, an experience can be assimilated by a mental structure only by closely resembling a previously assimilated experience. Similarly, a mental structure can accommodate to a new experience only if it can accomplish this accommodation by making a small change in its existing organization. These principles help explain why mental and environmental control processes should display a high degree of compatibility if they are going to interact. If proliferation and discovery are the result of assimilation and accommodation, then they

should occur only when a potential interaction is very similar to a previous experience. Such similarity however is just what compatibility implies.

The relationship in Piagetian theory among equilibration, assimilation and accommodation is easiest to understand through an analogy with Freudian theory. Freud believed in a perceptual conflict between a collection of impulses embodied in the id and a collection of critics embodied in the super-ego. The role of the ego is to mediate between the id and the super-ego acting on impulses when they would prove adaptive and inhibiting them when they would not. Similarly, Piaget believed in a perpetual conflict between one tendency to assimilate new experiences to familiar categories and another tendency to accommodate our categories to fit new experiences. The role of equilibration is to mediate between these two tendencies assimilating new experiences as long as they fit familiar categories and accommodating these categories when they do not. Thus just as Freud proposed the ego as a source of structural unity among conflicting mental agents, so did Piaget propose equilibration as a source of procedural unity among conflicting control processes.

The image of equilibration as a mediator illustrates how Piaget's theory is revolutionary in contrast to Newell and Simon's theory which is not. In almost all theories of control, the unity of the control process results from the state toward which the controlled behaviour tends. This fact is most evident in manmade control systems designed intentionally to achieve a specific state, such a target temperature in the case of the thermostat or the solution of a problem in the case of GPS. Although less obvious, it is equally true for psychological theories of mental and environmental control. The concepts of motivation and goal-directedness, essential for theories of mental control, attribute the unity in human action to putative needs and goals; likewise the concept of primary reinforcer serves the same function in theories of environmental control, which picture the unity of behaviour as derived from the tendency to accumulate rewards.

This instrumental conception of behaviour is also implicit in the theory of production systems. Newell and Simon's theory differs from most earlier psychological theories of control in that

it does not treat the human mind as a unified structure or human behaviour as a unified process. Rather it pictures behaviour as organized into discrete clusters, each of which is under the control of a particular production. Nevertheless to the extent that it does postulate unity in behaviour, that unity is instrumental. Whenever a system of actions is controlled by a single production, the unity of those actions results from the goal state toward which they tend.

In contrast, Piaget saw the unity of behaviour as resulting from a process of mediation (as did Freud). Piaget believed that behaviour tends in many directions at once, the most important of these being the tendency to assimilate and the tendency to accommodate. So that these competing tendencies promote adaptation, the mind needs a high level control mechanism capable of maintaining balance. Piaget used the term "equilibration" to designate this mechanism.

The difference between instrumental control and mediation sheds light on the control of Jonathan's and Toby's learning. To illustrate its significance, let us reconsider Jonathan's analysis of Mork's dancing. As we have noted, Jonathan's behaviour was influenced by various sources of control: first by his interest in Mork's realism; then by my asking whether a human foreigner would dance; and finally by his theory that the incident was exaggerated. In the long run, all of these figured as part of one unified process, namely Jonathan's acquisition of the fictional realism theme. But in the short run, they served competing purpose: Jonathan's interest led him to conclude that Mork's behaviour was realistic; my question hinted that it was unrealistic; and his "exaggeration" theory suggested that it was partially realistic, faithful to the essence but not the detail of Mork's personality.

The contrast between long-term unity and short-term competition explains the theoretical importance of both boys' experiences. As the last example shows, the short-term processes controlling their behaviour served short-term functions, such as evaluating the realism of a particular incident, functions orthogonal to such long-term effects as acquiring the fictional realism theme. This fact is highly discordant with the instrumental view of behavioural control which pictures short-term

functions as related to long-term ones only if the former serve as a means for the latter. But from Piaget's point of view, this contrast is exactly what one should expect. As his theory of equilibration argues, learning does not result from individual control processes operating in isolation but rather from the give-and-take among competitors.

But in itself, competition does not lead to long-term adaptation unless the competing control structures are themselves subject to a higher level of control. Therefore we should be surprised if Jonathan and Toby had acquired useful knowledge in the absence of some level of control higher than the ones already identified from the analysis of their protocols. We are now in a position to articulate the main relevance of Piaget's theory to the experiences of the two boys. In his concept of equilibration, Piaget gives us an image of a control mechanism which coordinates all other control processes, so that their interaction leads to long-term adaptation. This image provides the missing link needed to explain the unity in both boys' learning.

FIGURE 5.3

Deriving Equilibration from an Analysis of Learning:
An Overview

Learning — Section 5.2

Theme Discovery / Theme Proliferation — Section 5.4

Interest, Intransigence, Attachment, Local Variation — Section 5.5

Accomodation, Assimilation — Section 5.6

Equilibration — Section 5.7
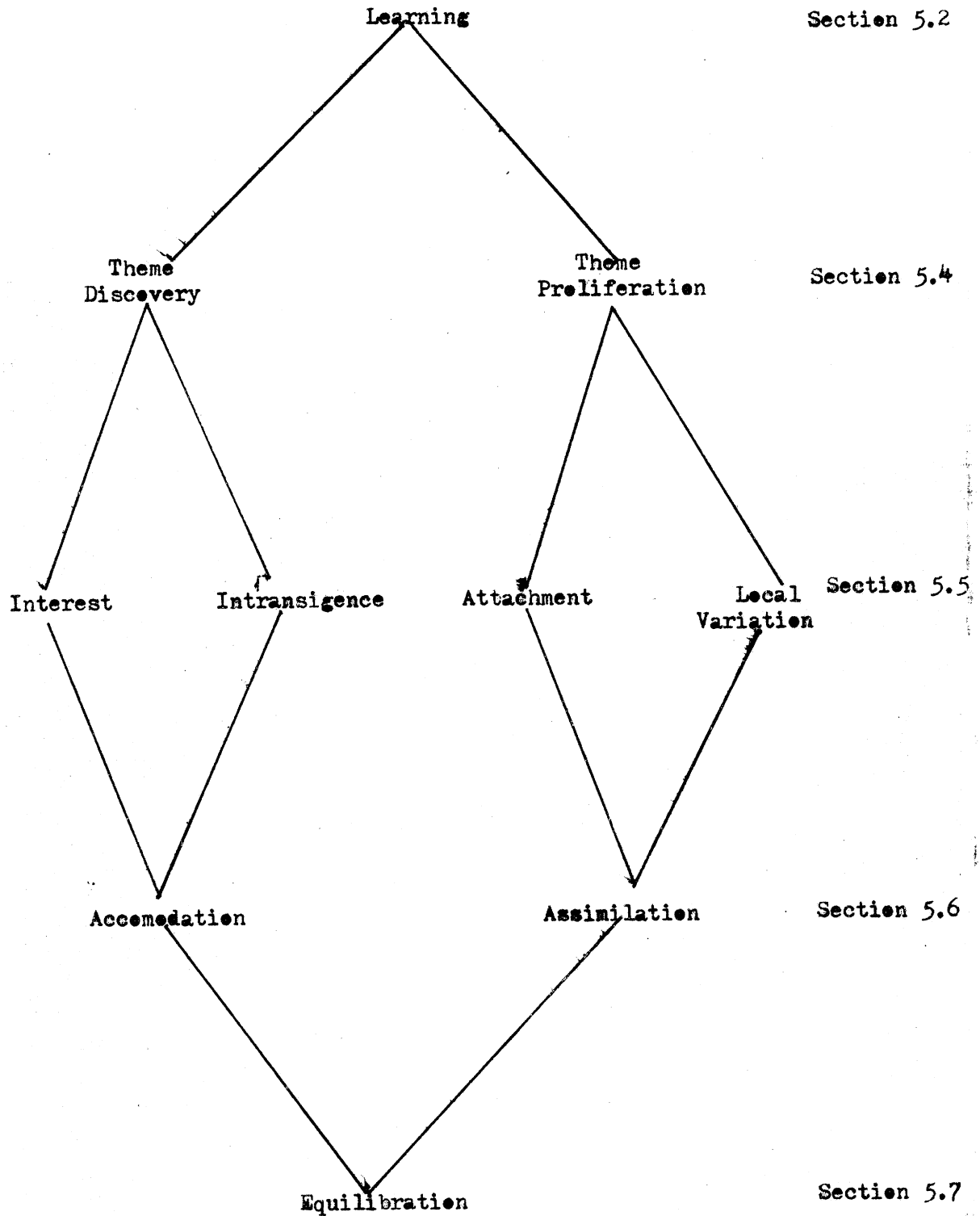
The diagram shown in figure 5.3 summarizes the steps through which my analysis will pass in deriving a theory of equilibration from an analysis of Jonathan's and Toby's learning. The first two steps serve to identify the theoretically important changes that I observed in the two boys' behaviour. These steps are (1) to state precisely what the two boys learned and (2) to distinguish two separable phases in their learning, the *discovery stage* and the *proliferation stage*. The remaining steps will describe control processes which appear to have caused these changes. My presentation will be "bottom-up" in that I will start with relatively low level control processes and move toward increasingly high levels of control. The lowest level will include the processes of mental and environmental control, which are *interest* and micro-world *intransigence* for the discovery stage and *attachment* and micro-world *variation* for the proliferation stage. The intermediate level will consist of interactive control processes, such as *accommodation* which results from the interaction between interest and intransigence, and *assimilation* which results from the interaction between attachment and variation. Finally, the highest level control structure will be the mechanism of equilibration, the basis theoretical framework for explaining the unity and adaptiveness of both boys' behaviour.

5.4 The Process of Transition

To understand Jonathan's and Toby's learning is to explain the process of transition. Before the study, Jonathan's comment about *Battlestar Galactica* would have been improbable just like Toby's experiment with bleach and iodine gas. By the end of the study, however, they both seemed perfectly in character. Therefore Jonathan and Toby both must have changed as a result of the research. The goal of my theory is to explain how the two research micro-worlds affected these changes.

We can begin to appreciate the influence of the micro-worlds by contrasting the opportunities given to the two boys at the beginning of the research from those at the end. During

the opening sessions, the novel elements of their experience came from the objects in the environment. Since many of these objects were unfamiliar and they were administered by an unfamiliar man, Jonathan and Toby faced both the opportunity and necessity of learning what good use could be made of them. However during the final sessions, novelty came not from the micro-worlds themselves which by now were familiar but rather from their new ideas, the realism theme and the purple smoke theme. Since themes, in contrast to micro-worlds, are a portable resource, they open the possibility of being tried in many different settings.

Complementing these differences in opportunities, there was a corresponding distinction in the style of innovation which both boys pursued. Early in the study, they spent their time sampling the various offerings of the two micro-worlds, following no chain of experiment or speculation very deeply but rather encountering a wide variety of effects. But later on, their behaviour became more focused, concentrating on the two or three themes that represented their major discoveries.

The difference in styles of behaviour between the initial *discovery stage* and the later *proliferation stage* helps to distinguish the short-term effects of the micro-worlds, encouraged by both boys' tendency to sample, was to point out relationships and distinctions which previously had been outside of their knowledge. Such a relationship was the causal connection between heating the mixture of sulfur and sodium iodate and the production of purple iodine gas; a comparable distinction contrasted weird fictional events from realistic ones. Thus the immediate effect was essentially an intellectual one since it represented a change in the state of their knowledge. The ultimate effect however was to change not only their knowledge but also their behaviour. The result of their new knowledge was the emergence of themes, such as making purple smoke and assessing fictional realism, which gained increasing control over Toby's and Jonathan's behaviour, first within the research micro-worlds and then outside of them. Hence the practical significance of the discovery stage became clear only during the proliferation stage; the effect of their discoveries was not only to begin thinking differently but eventually to start acting differently. stated in general terms, the two

stages correspond to differing levels of experience with a micro-world. The discovery stage is a time of exploration when the micro-world's secrets are fresh and new. The proliferation stage grows out of familiarity; during this final stage, after having extracted new concepts from the micro-world, one begins to apply them in numerous settings.

Both Jonathan and Toby entered the discovery stage full of preconceptions about how they might act. From his comments during the opening session, we know that Jonathan's initial understanding of Mork was quite superficial. He showed little interest in analyzing Mork's character, feeling satisfied to point out Mork's weirdness and to explain the various jokes. Toby entered the Chemicals World knowing of certain chemical reactions, such as the reaction between baking soda and vinegar, which he wanted to perform himself. He also knew that he could mix and heat the various compounds at his disposal; so he began heating various chemical mixtures semi-systematically.

Neither boy could anticipate where these opening activities would lead. If they enjoyed their initial exploration, as they did appear to do, their pleasure must have resulted from encountering essentially new experiences. I like to picture children as explorers discovering virgin terrain. The excitement comes from the hope that there is new wealth to be found if only they search carefully enough.

The main achievement of the discovery stage is the encounter with unexpected phenomena. Such a phenomenon for children is like a landmark for an explorer, an event in the micro-world which catches their attention. Once identified, they can introduce variation on the surprising event, just as an explorer can investigate the territory in the neighbourhood of known landmarks. Furthermore, as an explorer can map a terrain by discovering paths which connect landmarks, so can children understand a micro-world by observing connections among unexpected events.

The landmarks were compounds such as sodium iodate, purple smoke and bleach in the Chemicals World and characters such as Mork in the *Mork and Mindy* World, figures which

embodied the surprising events and which came to serve as objects of attachment. Once identified, these objects began to acquire new uses for both Toby and Jonathan. Toby began by experimenting with the purple gas he could now reliably manufacture. In one series of experiments, he poured the gas onto different surfaces, to discover what colour the surface would stain. In other experiments, he investigated the physics of pouring gases between containers; he learned that some gases are poured downward like liquids, while others are poured upward. Later he became interested in the odor of his purple gas.   Jonathan also exemplified new themes with the objects of his attachment. Of these new themes, the one

which he explored the most deeply was the concept of emotion learning.

Finding new uses for the objects of one's attachment is characteristic of the second phase in learning about a micro-world, the proliferation stage. Once they have become attached to specific objects, these objects begin serving as reference points from which themes can proliferate. Consider the effect of Jonathan's attachment to *Mork and Mindy*. Gradually, as the study progressed, Jonathan started applying his themes of realism and emotion learning to works of fiction less and less like the television program where they had first arisen. Toby too used his purple gas as a point of reference. During the fifth session, he generalized his theme of pouring gases to compounds other than his purple iodine smoke. During the last session, he used other chemicals to try to produce striking odors. For both Jonathan and Toby, the attachment objects served as foci from which their various themes could be generalized.

5.5 Mental and Environmental Control

In my previous discussion of control, I introduced the theory of equilibration and the perspective represented by the work of Jean Piaget as the basic conceptual framework for the present analysis. As I mentioned at the time, I have two justifications for adopting a Piagetian perspective. One is Piaget's interactive view of control, with its emphasis on the relationship between mental and environmental control; the other is that Piaget's theory directly addresses the problem of long-term adaptation.

Interactive control presupposes mental and environmental control structures capable of interacting; so I begin with a separate discussion of mental and environmental control, independent of one another. Although my approach to interaction is Piagetian, at this pre-interactive stage I will borrow mainly from other theoretical perspectives quite alien to Piaget's point of view.

The theoretical traditions from which I will draw most heavily are psychoanalysis and behaviorism. This choice is appropriate since psychoanalysts, more deeply than any other group of psychologists, have studied the mental control of behaviour and behaviourists, with comparable thoroughness, have analyzed the control provided by the environment. As the following discussion will make clear, my observations forced me to take an opposite stance toward psychoanalytic theories than I did toward behaviorism. Because of analogies between the descriptions published by Freud and my own observations of Jonathan and Toby, I was able to assimilate my categories of interest and attachment to similar concepts in psychoanalytic theory. However, I was unable to find equivalent similarities between behaviourist descriptions of control and the experiences of Jonathan and Toby. I have therefore chosen to present my description of environmental control in terms of a contrast rather than an analogy with Skinner.

5.5.1 Attachment and Interest

A central guiding principle in Freud's methodology was his belief in the continuity between normal behaviour and its pathological counterpart. His adherence to this heuristic of course was not absolute. He recognised that some pathological behaviour in fact was discontinuous with healthy behaviour; biochemical and neurological factors especially can cause behaviour qualitatively different from anything displayed by healthy people. Nevertheless he often found it useful to regard neuroses as exaggerated forms of normal mental processes, and therefore to see neurotics as unusual in their behaviour but not in their underlying psychological organisation. Thus Freud was able to use this principle to help explain neurotic symptoms of obviously disturbed and maladjusted people, as well as to study the apparently non-functional experiences of all human beings, such as dreams and slips of the tongue.

In my analysis of attachment and interest, I will follow Freud:'s heuristic in viewing these two normal emotions as continuous with two pathological states familiar in clinical practice. Sepcifically, I will picture attachment and interest as constructive equivalents of two states which long have been considered important by psychotherapists, obsession and compulsion. The essential characteristic of both obsessions and compulsions is their both being mental events which recur over and over again, independently of any conscious higher-level control. An obsession is a thought which keeps returning to one's mind, whether or not one wants to think it; a compulsion is an act which one keeps feeling the urge to perform, whether or not one wants to perform it. Obsessions and compulsions are both considered pathological because they interfere with normal functioning; they can become so intense that they will regularly arise at inopportune moments interrupting other ongoing activities. Attachment and interest are both constructive rather than pathological. An attachment is like an obsession in that the thought of an object keeps returning to one's mind if one is attached to it. Similarly, an interest is like an obsession in that one keeps feeling the urge to engage in

an action if one is interested in it. But unlike obsessions and compulsions, attachments and interests are not so intense that they interfere with other important objectives. They enter one's mind if and only if one is free to pursue them; otherwise they wait.

But before discussing the obsessiveness of attachments and the compulsiveness of interests, I will relate attachment and interest to similar more familiar psychological notions. Attachment and interest may both be seen as kinds of fondness; phenomenologically, we experience both of them as pleasant. In the past, the psychological effect of fondness has been studied most seriously within the framework of psychoanalytic theory. In fact, the process of transference, in which a patient displays feelings for the therapist indistinguishable from love, is relevant in the present context because, like interest and attachment, it represents an emotion which serves the function of control.

According to the psychoanalytic account of transference, the process happens when patients transfer the love which they had felt for a parent or sexual partner onto their therapist. Freud (1958) argued that transference is essential for psychoanalysis to be successful. Along with the love, patients also transfer the pathological feelings associated with the loved person onto the therapist. After transference, the psychoanalyst helps the patient to become aware of these pathological feelings and this process of increasing awareness leads ultimately to patients gaining relief from their neurotic symptoms.

The theory that emotions serve the function of control has influenced psychoanalytic research as well as psychoanalytic therapy, as illustrated by John Bowlby's (1969) analysis of attachment between an infant and its primary caretaker. Bowlby pictures attachment in human beings as analogous to the process of imprinting, discovered in ducklings as well as other species of birds and mammals. Just as newborn ducklings protect themselves by closely following their mother, so too do human infants avoid danger by remaining near their primary caretaker. Two behavioural patterns both of which emerge near the age of eight months provide the main evidence of attachment in human babies. The first, known as stranger anxiety, is the effort of babies to flee when approached

by a stranger. The second, known as separation anxiety, is the infants' display of anxiety when separated from their primary caretaker.

It is common to see attachment as contributing to infants' physical security and as providing a precursor for relationships both within and outside of the family later in life. But in addition to these social functions, it is possible that infant attachment serves a cognitive function through contributing to the acquisition of knowledge. We may recognise the intellectual significance of infants' attachment to their mother by comparing it with Jonathan's attachment to the television series *Mork and Mindy*.

As we have seen in earlier chapters, attachment objects serve as points of reference in the proliferation of themes. Thus not only does attachment have an effect on themes, causing them to become generalised, but it also influences novel contexts, suggesting which of their contents may be like familiar objects. This second effect of attachment, apparent in Jonathan's and Toby's behaviour throughout the proliferation stage, can be illustrated most clearly by re-examining Jonathan's descriptions of programs other than *Mork and Mindy* after his first signs of attachment. By comparing *What's Happening* and *Battlestar Galactica* to *Mork and Mindy*, he noticed aspects of these programs which could not otherwise have caught his attention. One such discovery was that the characters in *What's Happening* were developing from week to week just as Mork was learning new emotions. The significance of these observations in the proliferation of Jonathan's themes is apparent from his purpose in mentioning this similarity. As Jonathan told me, the changes in the characters made *What's Happening* appear realistic, almost as realistic as *Mork and Mindy*.

One difference between Jonathan's attachment to *Mork and Mindy* and infants' attachment to their mothers is that his memory of *Mork and Mindy* gave Jonathan themes for thinking while the physical presence of their mother gives infants a partner for interacting. Nevertheless they both serve to introduce familiarity into an otherwise novel setting. The continuity between these two examples of attachment is made clearer by considering an intermediate case, the attachment of Toby to purple

iodine gas.

Like Jonathan, Toby came to think often about purple smoke, even when it was physically absent. An interesting example occurred when Toby's discovery that his white smoke poured upward made him think about the purple smoke, whether it too would pour in the same direction. But in contrast to Jonathan's comparisons, Toby's memory of the purple smoke was not detailed enough to provide an explicit answer to his question. Toby was led to synthesis the purple smoke so that by physical experimentation, he learned that purple smoke pours downward.

A neurotic obsession may be seen as an extreme case of the same kind of attachment that Jonathan displayed. Like the thought in Jonathan's mind of *Mork and Mindy*, an obsession is a memory which keeps returning over and over again. The distinctive feature of an obsession however is the extent of its proliferation, so that it recurs in settings even which it can in no way help to understand.

On the other hand, interests are more like compulsions than obsessions. Jonathan's initial interest in demonstrating Mork's weirdness and Toby's interest in trying all the chemicals were important not as memories to be recalled in later settings but rather as actions producing effects on the research micro-worlds. The significance of these interests resulted more from their long term effect than from any short term consequences. Over the short run, the two boys expressed their interests by keeping constantly busy in the research micro-worlds. Over the long run, these interests had the important effect of providing precursors for the themes which later proliferated throughout their conceptual worlds.

The growth of Jonathan's realism theme illustrates how an interest can initiate the development of a theme. As we have already noted, Jonathan considered Mork weird and not the least bit realistic at the beginning of the study. Nevertheless, Jonathan's original interest in Mork's weirdness led eventually to his becoming attached to Mork as well as to the change in his judgment. The first important transition took place while Jonathan was analysing a dinner party arranged by

Mork, a party which Jonathan considered "weird". After pointing out the strangeness of Mork's behaviour and weirdness of the foods he served, Jonathan noticed a comment by Mindy, her statement that "Mork is honestly trying to cook a good dinner." For the first time, Jonathan attributed to Mork a human feeling saying "he really is trying to cook this dinner good." From that point on, Jonathan stopped describing Mork as weird and began pointing out how his behaviour was realistic. By perceiving Mindy's statement as a contradiction to his own existing belief, Jonathan was able to develop his more sophisticated realism theme.

The short term effect of interests becomes clear if we contrast the constant activity of Jonathan and Toby with the apparent boredom of my third subject, Leonardo. On many occasions, Leonardo had trouble staying focused on his work, often asking me, "what should I do now?" As the study progressed, the symptoms of Leonardo's boredom became increasingly severe. I list them in the same order as they apeared during the study.

(1) Requesting Direction

From time to time, Leonardo would ask me directly, "what should I do now?"

(2) Distraction

Leonardo often became distracted from the research by thoughts of unrelated subjects. While still in the Chemicals World, he described, at length,various classroom experiences, the movies he had recently seen and events in his family. During one session, he told me, "I can't wait 'til next year." When I asked why, his reason was that we would then be doing *Mork and Mindy*. This comment expressed more dissatisfaction with the chemicals than love for *Mork and Mindy*. As he told me during the television research, he did not really like *Mork and Mindy* very much.

(3) Uncommunicativeness

In the *Mork and Mindy* World, Leonardo usually gave terse, direct answers to my

questions. Unlike Jonathan and Toby, he failed to elaborate on his statements. Like a suspect under interrogation, he said exactly what was required of him and nothing more.

(4) Protest

Eventually, Leonardo complained overtly that he disliked the research.

(5) Avoidance

Late in the study, Leonardo began missing research sessions.

(6) Escape

Finally, Leonardo voluntarily withdrew from the research with two sessions still remaining.

By the end of the study, Leonardo's feelings had passed beyond boredom to obvious distress.

The results of this study do not help explain why Leonardo's boredom elicited precisely these symptoms. But even though the cause of his behaviour remains unknown, its effect on his learning is clear. Since Leonard was committed to no single interest as strongly as Jonathan was committed to demonstrating Mork's weirdness, he lacked the opportunity to encounter incidents suggesting alternative themes. Thus he missed the very experiences that proved so crucial to Jonathan and Toby as transition points in the development of proliferating themes.

Unlike Leonardo, Jonathan and Toby passed from the discovery stage to the proliferation stage. By keeping busy during the discovery stage, they acquired the themes which later proliferated through their conceptual worlds. But once they became attached to objects which exemplified these themes, the need to proliferate them made new psychological demands. During the discovery stage, it was better that their thinking not remain too focused because they could keep busy only by being open to a variety of interests. But during the proliferation stage, it was their thinking which became

highly focused. Only by thinking about the same theme in a variety of settings was it possible to have the theme proliferate. The effect of their feeling of attachment was that they kept recalling an object which exemplified their themes in a variety of settings.

Both Jonathan and Toby displayed four typical signs of attachment. These symptoms were apparent in Toby's treatment of the purple gas, in Jonathan's discussion of *Mork and Mindy* and in both boys' behaviour toward their other objects of attachment. The actions indicative of attachment are the following.

(1) Frequency of Use

Both boys used their attachment objects far more often than any others. During the research sessions, a high proportion of Toby's experiments made use of the purple gas. Outside of the research, Jonathan not only watched *Mork and Mindy* regularly but also thought about the program when he was not watching television.

(2) Reference Point

They understood new experiences by comparing them with their attachment objects. Toby analysed new gases by comparing their properties with those of his purple gas. Jonathan evaluated television programs by comparing them with *Mork and Mindy*.

(3) Self Description

Both boys said explicitly that they had special relationships with the objects of their attachment. Toby said

that the purple gas was his favourite chemical. He reaffirmed his identification with the gas by calling it "my purple smoke." Jonathan said explicitly that he had become attached to *Mork and Mindy*.

(4) Praise

They both praised their objects of attachment. Toby used his purple gas to impress his classmates. Jonathan explained at length the reasons why *Mork and Mindy* is so good.

5.5.2 Intransigence and Local Variation

A famous change in the history of behaviorism, from the time of John B. Watson to B.F. Skinner, was an enriched conception of the basic behavioural unit, the response. Watson was often ridiculed for being a "muscle-twitch" theorist because he saw conditioning as establishing a rigid pattern of muscular contractions. In contrast, Skinner described responses not in physiological terms but rather functionally. For him, the identity of a response came not from the muscles it required but from the effect it produced on the environment. The main practical consequence of this functional point of view was the development of the Skinner box as an instrument for analyzing conditioned behaviour. The purpose of a Skinner box is to differentiate an environmental effect of interest, such as the depression of a bar, from a complex field of other environmental effects. Since Skinner conditioned animals to control their environment rather than contract their muscles, he needed an instrument which could isolate distinct environmental events.

One may picture the forthcoming analysis of environmental control processes as an assimilation of a fundamental Skinnerian distinction into an otherwise anti-Skinnerian theoretical framework. This act of assimilation will be possible by recasting Skinner's idea as a contribution not to behavioural analysis but instead to environmental description. Like Skinner, I want to differentiate between form and function. However by form, I will refer not to patterns of muscle contractions but rather to the material contents of micro-worlds; and by function, I will mean not environmental effects but rather the intellectual content embodied in material objects.

Why should we consider micro-worlds to be autonomous units of experience separable from the other parts of a person's environment? One basis for distinguishing a micro-world is the

material objects it contains. The Chemicals World could be identified as a collection of physical objects such as beakers and test-tubes and chemicals; the *Mork and Mindy* World as a collection of people such as Mork, and Bickley and Exedor. It is important not to dismiss or neglect this formal level of description because it does serve a legitimate purpose. If other learners, or teachers, want to reproduce the lessons of Jonathan and Toby, recreating the same material conditions may be an important first step. On the other hand, neither should we presume, as John B. Watson did, that a formal description contributes to a functional explanation. Micro-worlds contribute to learning not because of the objects but rather of the ideas which they embody. We can begin an analysis of environmental control processes only by identifying the fundamental ideas which unified each of the research micro-worlds.

Consider first the Chemicals World. Although many actions were possible in the Chemicals World, there were two obvious activities to pursue, ones that all three boys identified from the beginning of the first session; these were heating and mixing chemicals. That the micro-world encouraged these activities had a powerful effect on what discoveries would be likely. The connection between heating and mixing is that both activities produce interesting chemical effects but not physical ones. Many chemical properties of a compound, such as its colour, odor, specific gravity and viscosity could be recognizably changed by heating and mixing; however none of its physical properties could be affected by these actions in any interesting way.[1] It therefore is not surprising that the phenomena which interested Toby were all chemical and not physical. These included colour changes, state changes from solid to liquid to gas, odor changes and the relative densities of different gases. Thus despite the heterogeny of materials in the Chemicals World, the environment remained distinctive because of its underlying conceptual unity. The many experiences

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1. None of course except its temperature. A hot chemical has the interesting and dangerous property of causing burns. The subjects were prevented, by their own common sense as well as my restraint, from discovering the effects of high temperatures on the simple grounds of safety.

possible in the micro-world all exemplified one central theme, an idea often considered the most basic Chemistry, namely the distinction between chemical properties, which heating and mixing could alter, and physical properties, which they could not.

This distinction began to control Toby's thinking from the very beginning of the research. As I have already shown, a critical step in Toby's learning to make purple smoke was to replace his conservation of colourfulness theory, the theory that colourful compounds when heated become colourful gases, by the realization that the chemicals themselves, and not their colour, was responsible for the reaction. The difference between Toby's early theory and his later one corresponds to a familiar difference between professional Physicists and Chemists; that physical explanations often include quantities being conserved and chemical explanations usually identify substances that have been transformed. Nor should this correspondence be considered a mere coincidence. The differing styles of explanation in professional science result from the same fact that caused Toby to revise this theory. Even great differences among substances, differences as great as between galaxies and billiard balls, does not qualitatively affect their physical behaviour; however even small differences affect their chemical behaviour. Therefore to control physical phenomena, it is usually best to ignore these differences; however to control chemical phenomena, as Toby learned, the differences among substances must be kept in mind.

The rejection of the conservation of colourfulness theory illustrates one process through which the Chemicals World influenced Toby. At the beginning of the study, Toby tended to neglect the identities of the compounds he was mixing. He would notice many of their properties, such as their colour, their bubbliness and their shininess, but he ignored their names. In Chemistry, however, where differences in effect result from differences among compounds, this neglect makes phenomena impossible to reproduce. The intransigence of the Chemicals World to this neglect of differences among compounds was the first means through which the micro-world influenced his thinking and behaviour.

This process of intransigence was the first of two environmental control processes exemplified by the research micro-worlds. Intransigence can be described most easily by contrasting it with reinforcement. In theories like Skinner's, a reinforcer is an environmental event which increases the frequency of some act; in contrast, intransigence is a process which hastens the modification of a behavioural pattern. Similarly intransigence is effective in changing behaviour for essentially the same reason as reinforcement is effective in maintaining it. The most popular reinforcers are ones like food which serve some pre-existing need. By analogy; one may expect the most effectively intransigent micro-worlds to the ones which frustrate some pre-existing interest.

Certainly Toby's experience in the Chemicals World supports this expectation. It seems clear that Toby paid attention to the sodium iodate only because his interest in making purple smoke would otherwise have remained frustrated. This theory of intransigence gains further support from the experiences of Jonathan. To illustrate the effect on Jonathan of intransigence, I will reconsider his initial discovery of fictional realism.

Jonathan began the research interested in showing that Mork was weird and non-human but the facts of the *Mork and Mindy* World proved intransigent and obstructed his interest. The micro-world first undermined his analysis of the dinner party incident when Mindy remarked that Mork's weird dishes were inspired by his genuinely human desire to please. This idea was further obstructed by my asking if Mork, the spaceman, would realistically behave differently from a Chinese visitor when watching a basketball game.

Just as the Chemical World's intransigence resulted from the conceptual unity provided by the physical/chemical distinction, so did the intransigence of the *Mork and Mindy* World result from its unifying concept, the idea of Mork's essential humanity. Although Mork often exhibits behaviour entirely unexpected from a human being, it is not caused by an fundamental difference between his nature and ours. The misdeeds of Mork, such as dancing at a basketball game or taking home a pet caterpillar, are the kind of behaviour that could and does occur to human beings, but gets suppressed

by our knowledge of social conventions. The unusual and interesting fact about Mork is his total ignorance of these conventions. Mork's discovery of human conventions provides both the humour and pathos of the series.

The effect of intransigence is to provoke the discovery of new ideas and novel behaviour patterns. But once these themes have been encountered and the discovery stage ends, a different environmental control process begins to exercise its influence. This second process I call *local variation*.

Just as the conceptual unity of both micro-worlds made them intransigence to Toby's and Jonathan's initial maladapted interests, so did their material heterogeny make them supportive of both boys' later well-adapted attachments. A common of both micro-worlds is that their material contents continued to vary. In the *Mork and Mindy* World this variation came from the intrinsic structure of television series, since each new episode necessarily introduced events slightly different from the previous ones. In the Chemicals World, it was caused by Toby's own experimentation since each week he produced fresh compounds slightly different from the ones he had made before. THis process of variation created a long series of new contexts, marginally different from earlier familiar ones, in which Toby could try his purple gas theme and Jonathan could use his fictional realism theme. In the long run, this process of local variation produced such a broad range of contexts that some of them were quite like settings from everyday life. It was from these settings that Jonathan and Toby generalized their themes to settings outside of the research.

One of the central empirical results of this study is that this process of generalization followed a systematic pattern. In Tables 5.1 and 5.2 I have listed the instances of two proliferating themes, one taken from Jonathan's learning and the other from Toby's. Beside each instance, I describe the current context. These tables show graphically the pattern of local variation.

TABLE 5.1

The Proliferation of Jonathan's Fictional Realism Theme

The left-hand column lists the instances of the theme. The right-hand column describes the type of context to which the theme was being generalized.

Instance of Theme	Type of Context
1) Basketball Joke	action of Mork's
2) Mork visiting Friends of Venus	action of Mork's
3) Mork thinking caterpillar dead	action of Mork's
4) Behaviour of rabbi at funeral (as portrayed by Mork)	action of character played by Mork
5) Accusation of theft	action of Mork's
6) Bickley stealing necklace	action of character other than Mork
7) Mork's description of wedding	action of Mork's
8) Eugene and Holly deciding to marry	action of characters other than Mork
9) Fifth episode	episode
10) Fourth episode	episode
11) Third episode	episode
12) Sixth episode	episode
13) *Mork and Mindy* in general	series
14) *What's Happening*	series other than *Mork and Mindy*
15) Angel movie	medium other than television
16) *Battlestar Galactica*	series other than *Mork and Mindy*

TABLE 5.2

The Proliferation of Toby's Theme of Heating the Mixture of Sodium Iodate and Sulfur to Make Purple Iodine Gas

The left-hand column lists the instances of the theme. The right-hand column describes the type of context to which the theme was being generalized.

Instance of Theme	Type of Context
1) trying out new chemicals	potential gas-producing mixture
2) After noticing purple smoke	potential gas-producing mixture
3) After heating sulfur in isolation	potential gas-producing mixture
4) After first successful replication	variation on purple smoke reaction
5) After second successful replication	potential gas-producing reaction
6) An addition to a mega-mixture	variation on purple smoke reaction
7) After adding gas ingredients to mega-mixture	variation on purple smoke reaction
8) After adding more gas ingredients	variation on purple smoke reaction
9) After failure of mega-mixture to make smoke	variation on purple smoke reaction
10) In presence of classmates and in a corked test tube	variation on purple smoke reaction
11) Starting a fresh session	variation on purple smoke reaction
12) In a corked test tube	variation on purple smoke reaction
13) After mixing vinegar and baking soda	variation on purple smoke reaction
14) After making white smoke	purple smoke created for later use
15) After making more white smoke	purple smoke created for later use
16) Three months later	purple smoke created for later use
17) After mixing baking soda and vinegar	gas-ingredients mixed although purple smoke was not wanted

18) After making a mega-mixture   gas-ingredients mixed although purple

19) To pour gas   purple smoke created for later use

20) In presence of classmates   variation on purple smoke reaction

21) After classmates noticed smell of smoke   purple smoke created for later use

22) After initial failure to smell up school   purple smoke created for later use

At first glance, these two tables may seem to exemplify a well-known and well-documented psychological phenomenon, the generalization gradient. Both tables show that a reaction—the reaction of Jonathan was to think about fictional realism and the reaction of Toby was to make purple smoke—was given in response to a broader and broader range of contexts. Such a pattern may seem a particular case of the familiar pattern studied primarily through animal research in which a response becomes elicited by an increasingly broad range of stimuli. A good example of this pattern would be an experiment in which a pigeon first learns to peck a key when shown a blue light and then gradually generalizes the response to light of increasingly long wavelengths, first green light, then yellow light and then orange light. This pattern is called a generalization gradient because each new stimulus differs from its predecessor in the same direction along the same linear dimension. In the hypothetical pigeon experiment, the dimension was lightwave-length and the direction was toward increasing length.

The first difficulty with this interpretation appears when we try to specify the dimension along which their reactions are generalizing. Consider the first three instances of Jonathan's fictional realism theme. Is there some dimension along which this theme is generalizing? As table 5.1 indicates the most obvious relation among these instances is not an ordinal one, as one finds in a generalization gradient, but rather one of similarity. The basketball joke, Mork's visit to the friends of Venus and Mork's thinking the caterpillar, was dead resemble each other because they all are actions of Mork. Likewise, the most obvious relation among the first three instances of Toby's purple gas theme is one of similarity rather than order. The three experiments are all similar because they all involve the heating of sulfur. But there is no linear gradient along which these experiments can be ordered.

Piaget's phrase "*de proche en proche*" describes the proliferation of Jonathan's and Toby's themes more accurately than does the generalization gradient. Literally, *de proche en proche* means "from near to near." The phrase pictures a mind as a spatial array in which it is easier to relate near

concepts to each other than distant ones.

Piaget developed this phrase from his studies of class inclusion (Piaget and Inhelder, 1959). A major result from this research is that children understand the inclusive relation between near classes at an earlier age than between distant classes. Thus relatively young children accept that there are more birds than either robins or sparrows in a collection that contains five robins and four sparrows; but only older children realize that there are more animals than either dogs or sparrows in a class that contains five dogs and four sparrows. The term "nearness" refers to two measures of proximity. One of these is the horizontal dimension of similarity. It is easier to compare robins to sparrows than dogs because robins and sparrows are more similar. The second is a vertical dimension which lacks an established name but we will call "inclusiveness." It is easier to relate sparrows to birds than to animals because the class of birds is only slightly more inclusive than the class of sparrows but the class of animals is much more inclusive.

As in Piaget's study, the themes of Toby and Jonathan proliferated not uniformly along a gradient but rather locally; in Piaget's terms "*de proche en proche*." Both Jonathan and Toby proliferated their themes to similar contexts before dissimilar ones. The first extensions of Jonathan's realism theme were from one action of Mork to another, two events which are quite similar; only later did he generalize the theme to such contexts as actions of characters other than Mork and to characters from other television programs, both of which are far less similar. Likewise, Toby's first proliferations of his gas-making theme were quite similar to the experiment in which he discovered the phenomenon. With only me watching him, he would make a chemical mixture differing at most from his opening experiment by only two ingredients, in an un-corked test tube; later of course, he used a wider range of chemicals, a variety of recipients and a number of different social settings.

It is also true, I think, that themes proliferate locally using inclusiveness as a measure of nearness although this conclusion is in principle more difficult to support. In Piaget's animals micro-world, there is a natural inclusiveness hierarchy, expressed formally in the Linnaean

classification of species, and used informally throughout Western culture. Because of this hierarchy's familiarity, Piaget had a sound basis for guessing the levels of inclusiveness which his subjects would adopt. But in my two experimental micro-worlds, there are no familiar inclusiveness hierarchies. I believe nevertheless that we can guess with considerable confidence the levels of inclusiveness used by Jonathan and Toby.

To illustrate how we might make this guess, I will consider four instances of Jonathan's realism theme: Mork's visit to the friends of Venus, Bickley stealing the necklace, the series *What's Happening* and the movie about the angel. If we imagine that Jonathan's theme is proliferating locally, we could see each of these instances as representing generalization at an increasingly higher level of inclusiveness, The first was the level of actions of Mork's; the second the level of actions of a *Mork and Mindy* character; the third the level of television programs; the fourth that of fictional media. It is a fact that each of these levels is more inclusive than its predecessor. Our ability to construct such an inclusiveness hierarchy I consider highly suggestive evidence in support of the theory of local variation.

I have devised a larger inclusiveness hierarchy for Jonathan's realism theme as well as Toby's gas-making theme. In tables 5.1 and 5.2, each instance of a theme has been assigned a "context type" where the type of context refers to its level in an inclusiveness hierarchy. As the tables illustrate, both Jonathan and Toby generalized their themes at increasingly high levels of inclusiveness as the study progressed.

The phrase local variation clearly describes theme proliferation more accurately than could a generalization gradient. It is possible to view each new instance of a theme as differing locally, either in similarity or inclusiveness, from a predecessor. It is not possible to construct a linear gradient along which themes become generalized.

Thus the local variation of the environment has essentially the opposite effect on theme proliferation as its intransigence had on theme discovery. The effect of intransigence was basically a

subversive one. It served to demonstrate the maladaptiveness of both boys' earliest ideas thereby forcing them to discover deeper ones. In contrast, the effect of local variation was a supportive one. It gave Toby and Jonathan the opportunity to use their themes in broader and broader range of contexts, ultimately exceeding the bounds of the research micro-worlds. Its effect was not to undermine their ideas but rather to demonstrate their power.

5.6 Assimilation and Accommodation

Consider my argument as I have been presenting it up to now. Thus far, I have pursued two goals almost independently of one another. Part of the time, I have represented my thesis as a report of a case study, in which I have described the experiences of two boys and noted the similarities between them. The rest of the time, I have conducted a literature review synthesizing contributions from highly diverse theoretical traditions on the grounds that they all helped to explain the control of behaviour. If taken separately each on its own merits, these two enterprises could justifiably be questioned. One could criticise the case study for being too local, yielding no definite conclusion which further research could generalize; on the other hand, one could take exception to the literature review for the very opposite reason, namely that control is so complex a problem that Psychology cannot hope to begin solving it for a very long time. But taken together, the value of these two projects becomes apparent. The value of the case study was to clarify a problem for control theorists, the problem of natural learning, by illustrating a behavioural process which the established theories of control cannot explain. Conversely, the value of the literature review was to help solve that problem, assembling a collection of theoretical contributions useful in explaining the control of natural learning. In the next two sections, I will make explicit the relationship between the behavioural processes identified in the case study and the control theories described in the literature review. In the end, I will argue that the discovery of this relationship provides the needed

justification for the entire thesis.

The first task in relating theory to data will be to distinguish two proposed control processes, each adapted to one of the two observed stages in Jonathan's and Toby's learning. Recall that the difference between the discovery stage and the proliferation stage consisted in the boys' reactions to particular experiences. During the discovery stage, both boys reacted to their most salient experiences by changing their own thoughts and actions. Just as Jonathan reacted to our discussion of Mork's dancing by revising his assessment of the event's realism, so did Toby respond to the appearance of purple smoke by trying experiments that would not have otherwise occurred to him. But during the proliferation stage, they varied not their own thoughts and actions but rather the environmental context in which these were expressed. The most characteristic property of this stage was that both boys concentrated on generalizing specific themes, the realism theme in the case of Jonathan and the purple smoke theme in the case of Toby. As we observed in an earlier section, Piaget's distinction between assimilation and accommodation corresponds to the difference between these two reactions. Accommodation is a process of revising one's own thoughts and actions; assimilation on the other hand generalizes existing themes to new contexts.

Piaget was not the first psychologist to distinguish two opposing reactions to experiences; indeed the behaviourists' distinction between conditioning and extinction also presented two contrasting reactions in terms much simpler than Piaget's. Piaget's theory however did represent an important advance over the earlier idea of the behaviourists. Unlike conditioning and extinction which are behavioural responses, assimilation and accommodation are mental responses. Therefore in contrast to the behaviourist processes which lead only to a change in behaviour, the Piaget processes lead to a change in the underlying control structures which direct action.

To analyze the effect of particular experiences on underlying control structures, I propose to reconsider an example which by now should appear familiar: the joke about Mork's dancing which led Jonathan to distinguish realistic events from exaggeration. Let us reconstruct the scenario. Mork

had returned home from a basketball game, shocking Mindy and her friend by relating that his favourite part was the dancing. Ad he soon explained that part was "at the beginning when everybody stood up and they played the music: oh say can you see." Jonathan thought at first that Mork's reaction was genuinely realistic. "When they stand up and play the music, you might think you're supposed to dance." Then I asked him, "Let's say a Chinese was visiting America, that's what they'd think?"

Before asserting in positive terms how my question did affect Jonathan, I want to describe in negative terms how my question did not influence him. Stated simply, my question did not extinguish Jonathan's idea. The absence of extinction is clear from both the long-term and short-term changes in his behaviour. Over the long term, the idea of fictional realism re-appeared over and over again in Jonathan's speculation; and over the short term, he never gave up the correct idea that Mork's behaviour did indeed remain faithful to his essence. However in rejecting the theory of extinction, I do not wish to suggest that my question in no way undermined Jonathan's hypothesis. I am asserting only that it undermined Jonathan's idea without extinguishing it, an effect never considered in behaviourist theories of learning.

In fact, the encounter between Jonathan's thesis and my question produced an effect beyond the scope of many popular theories of how experiences influence learning. The behaviourist theories of learning comprise only one part of this class of theories. Another member of this class is the view of learning as hypothesis testing. A third is Karl Popper's claim that experiments are important for science in providing an opportunity to falsify theories. These theories are all essentially similar because they all picture learning as a trial-and-error process.

I can discuss most easily this essentially similarity by introducing an image representing a court of law. Trial-and-error theories picture experiences as contests between rival claims much like civil suits where one claim is advanced by the plaintiff and an opposing one is maintained by the defendant. In trial-and-error theories, the role of the plaintiff takes the form of an action of the

learner; within behaviourist theories, these actions are called responses and in other theories, they have been called "hypotheses" and "conjectures"; the relationship among these various concepts is that they all represent mental control processes. Conversely the role of the defendant within these theories is played by the environment; terms such as "reinforcement" and "refutation" which designate the behaviour of the environment all represent environmental control processes. Experiences such as Jonathan's are seen as contests which judge either the adaptiveness or the truthfulness of the mental process in suiting the environment. The significance of an experience comes from its role as arbiter, either reinforcing the claim of the learner or ruling it to be in error. From this point of view, an experience truly is a trial and its result is genuinely a verdict.

But Jonathan's discussion of Mork's dancing led not to a rejection of the fictional realism theory, not to the conclusion that it did not apply to Mork's dancing, and not to a decrease of interest in Mork. In sum, it did not lead to the verdict that the theory was false. Instead it led to almost the opposite reaction. By the end of the session, Jonathan had decided that his theory was essentially sound but in need of slight revision. Mork's behaviour was not absolutely realistic but rather hyper-realistic, an exaggeration of Mork's real personality. Furthermore, by the end of research, instead of losing interest in Mork, Jonathan let his interest become amplified. As we have previously discussed, the dancing joke was an important turning point in Jonathan becoming attached to Mork.

To portray accurately the experience of Jonathan, I wish to propose a new image as an alternative to the view of experiences as trials. My image picture experiences as processes of reconciliation between the wishes of a learner and the constraints of an environment. The main difference between the trial image on the one hand and the reconciliation on the other is that reconciliation allows the possibility of change. Within trial-and-error theories, the learner and the environment must either fit one another or not; there is no middle ground. But within reconciliation theories, a mismatch need not be eternal because the possibility always remains for either the learner or the environment to change. Thus theories of reconciliation include a third control process in

addition to the two contestants, the mental and environmental control processes, which trial-and-error theories recognize. This third control process is the interactive one which directs the needed modifications leading toward greater reconciliation.

The theoretical significance of Jonathan's analysis of the dancing joke is in helping us to formulate a theoretical description of this third control process, the process of accommodation. As a result of his analysis, Jonathan altered the state of his relationship with one person in the *Mork and Mindy* World, myself, from an early point when we differed about the realism of Mork's behaviour, to a later time when this difference was overcome. This process of difference reduction is reminiscent of one well-known control process, the General Problem Solver of Newell, Shaw and Simon. In making this obobservation, I am not claiming that GPS and accommodation are identical with one another; instead I see GPS as a particular example of accommodation, in fact a particularly simple example, much simpler than is typical and certainly much simpler than Jonathan's analysis. I use GPS as a point of reference with which to compare Jonathan in order to clarify the distinctive properties of Jonathan's experience.

One important difference between GPS and Jonathan is derived from a fact discussed in an earlier section, that GPS is a special-purpose system whereas Jonathan is a general-purpose one. Thus GPS is designed to reduce differences only in micro-worlds such as propositional logic or cryptarithmetic to which it has been pre-adapted, but Jonathan, during the incident in question, was functioning in a micro-world to which he had just been introduced. Jonathan's newness in the *Mork and Mindy* World placed an added burden on him not shared by GPS. GPS begins work with a list of difference-types commonly encountered and of operations useful in reducing these differences; Jonathan, on the other hand, was forced to discover both difference-types and productive operations in the process of solving his problem. We see then that GPS had but one problem solve, to eliminate the difference between the current state and the goal state; however Jonathan also had a derivative problem, to identify the difference-type along with a difference-reducing procedure.

The existence of this derivative problem was a factor making Jonathan's task more difficult than the work of GPS. However there was a second factor offsetting the first, in making Jonathan's task less demanding. The micro-worlds suitable for GPS all present problems in sequencing; by that I mean that the solution must come from discovering the correct order for applying a sequence of operations. In contrast, Jonathan's problem could be solved by applying just one operation: he had to find a single transformation of his own theory that would satisfy my objection. The significance of this fact is that it allows the control structure of accommodation to include one less step than GPS. Since GPS solved problems of sequencing, one could expect, at least most of the time, that the next transformation would not entirely reduce the difference between the current state and the goal state. There would usually be some remaining difference to be reduced by the next transformation in the sequence. But in accommodation, the discrepancy between the required transformation and the current state-goal state difference would not exist. Therefore, unlike GPS, the identification of the current difference would be equivalent to discovering the transformation which solves the problem.

These last two considerations suggest a two-step process which could have provided the top-level of control for Jonathan's accommodation to my objection. The first step, the one that activated his tendency to accommodation, was his noting an incompatibility between his theory that Mork was behaving realistically and my pointing out that a Chinese visitor in Mork's position would not have danced. His next step was to formulate a theory of how to transform his theory to meet my objection; he did this in determining that Mork's behaviour was exaggerated, hyper-realistic, rather than genuinely realistic.

This description of accommodation may seem trivial or even question-begging to some readers. They may argue that the real mystery is how Jonathan discovered his theory of exaggeration once he had recognized the need to accommodation. I would agree with these critics that the process which brought to his mind the concept of exaggeration is indeed a mysterious one but that fact does not undermine the value of my explanation. The mystery raised by this objection is a mystery not

about learning but rather about memory. It is a particular case of the familiar problem of memory retrieval, a well-known and complicated problem far beyond the scope of the present thesis. Nevertheless, my analysis represents a contribution to knowledge in showing that one familiar problem, the problem of accommodation, can be reduced to an apparently unrelated problem, the problem of memory retrieval.

My description of the process of accommodation can be applied not only to Jonathan's analysis of Mork's dancing but in fact to every time during the research when an interest of one of the two boys produced a reaction of intransigence from their micro-world. This process was apparent on such occasions as when Toby's conservation of colourfulness theory first failed or when Jonathan began to doubt his belief that Mork experienced no emotions. Whenever interest and environment collided, both boys reacted by formulating new theories as when Toby speculated that sulfur plus sodium iodate made purple smoke, or when Jonathan postulated that Mork was learning emotions. In every case, their theories were finely tuned to answer the bug that the environment demonstrated.

The main moral of this discussion asserts that accommodation is not a trial-and-error process because it is intelligent. Rather than producing total acceptance or rejection of an idea, it leads to a more sophisticated understanding of how the idea is partially right and how it is partially wrong. The experiences of Jonathan and Toby show that people show the same subtlety in reacting to harmonious encounters with the environment as they do in accommodating to environmental intransigence. Just as trial-and-error theories would predict, Jonathan and Toby tended to re-apply their well-adapted themes with increasing frequency. But beyond what these theories would have one expect, their patterns of theme proliferation revealed underlying process of intelligent theorizing which led them to generalize their theories more and more broadly.

I will now use an analogous strategy for developing a description of assimilation as I have just adopted for developing a description of accommodation. Specifically, I will compare an example of assimilation, the proliferation of Jonathan's fictional realism theme, with a well-understood control

process; in this case, it will be negative feedback. The justification for comparing assimilation with negative feedback is the same as the justification for comparing accommodation with GPS. Just as accommodation and GPS share the function of reducing differences, so do assimilation and negative feedback share the function of preventing differences from arising. Furthermore both comparisons serve analogous needs within the present argument. Just as GPS served as a simple limiting case of accommodation, so will I present negative feedback as a simple limiting case of assimilation.

To simplify my analysis, I will focus my attention on two steps in the proliferation of the realism theme just as my analysis of accommodation concentrated on Jonathan's reaction to one specific question. The events to be examined are first Bickley's stealing Mindy's necklace during the fourth episode, which Jonathan considered unrealistic, and second the story about Eugene's wedding taken as a whole which Jonathan judged "not real-life realistic but show realistic; for the characters in the show and the way the show goes, this is the most realistic." The reason for choosing these particular events is that they represent the two directions in which Jonathan's theme proliferated: Bickley's theft was typical of horizontal proliferation, along the dimension of similarity, from one *Mork and Mindy* character to another; Eugene's wedding was typical of vertical proliferation, along the dimension of inclusiveness, from one program element, the character Mork, to an entire episode taken as a whole.

Like our example of accommodation, both instances of assimilation resulted from an interaction between a mental control process and an environmental one. In the case of accommodation, these processes were the two control processes characteristic of the discovery stage, interest and intransigence; and the ensuing accommodation was caused by a conflict between them. By analogy with accommodation, assimilation was activated by an interaction between attachment and local variation, the two control processes characteristic of the proliferation stage. But in contrast with accommodation, the ensuing assimilation was caused not by a conflict but by a surrender of the environment to Jonathan's theme.

I can make more concrete the distinction between conflict and surrender by contrasting the responses of interest and attachment to novel environments. And to add vividness to this contrast, I will anthropomorphize interest and attachment, the former in the guise of a gregarious person and the latter in the position of a reticent one. Like gregarious people who enter easily into social interactions, so do interests enter easily into intellectual interactions; and like reticent people who tend to shy away from new relationships, so do attachments tend to avoid new interactions, except with environments reminiscent of their attachment object. These contrasting intellectual styles lead to opposite patterns of interaction, analogous to the contrasting social styles of gregarious and reticent people. Like gregarious people, interests tend to have many interactions, some of which are inevitably hostile; on the other hand, attachments, like reticent people, are selective in when they interact, but the interactions they have tend to be harmonious.

The purpose in introducing this metaphor is twofold. First it provides a framework for connecting two findings from my study, (a) the observation that interests kept re-appearing more rapidly during the Discovery stage than themes did during the Proliferation Stage with (b) the infrequency of conflicts during the Proliferation Stage relative to the Discovery Stage. But second, and more significantly, it gives us a point of view for relating attachment to local variation, and thereby for explaining the interactive control of theme proliferation.

In contrast to interests, which are undiscriminating, attachments avoid interacting with objects except when they are closely related to the object of the attachment. This property of attachment suggests a reason for Jonathan proliferating his theme of realism to both Bickley's theft and the wedding episode. Since he was then attached to the character, Mork, we would expect him to proliferate the theme of realism, already associated with Mork, to other objects connected with the Orkin. Now Bickley and the wedding episode are both such objects. Bickley was connected by the relationship of similarity, their both being *Mork and Mindy* characters; and the wedding episode was connected by the relationship of inclusiveness, Mork being a part of the wedding story. We are now

in a position to describe the role of local variation in theme proliferation. Micro-worlds, like the *Mork and Mindy* World keep introducing objects slightly different from familiar ones, through the process of local variation. Some proportion of these new objects are enough like the object of attachment to support the proliferation of its themes. Since these objects of necessity are well adapted to the assimilating theme, it follows that the interactions of the Proliferation Stage should be harmonious.

This interactive account of theme proliferation is useful in providing a richer explanation of generalization than any previous psychological theory. Although previous researchers have studied generalization, they have mostly been behaviourists and therefore ideologically opposed to the construction of complex theories. Admittedly the present study permits only a schematic description of how attachment and local variation interact. I believe, however, that my account fits closely enough the experiences of Jonathan and Toby to justify the further development of my theory.

The relationship between negative feedback and assimilation is that both control processes serve to identify likenesses. Just as thermostats compare room temperature with a target temperature, so does assimilation compare novel objects with objects of attachment. This similarity permits us to treat negative feedback as a limiting case of assimilation, from which to derive our description of the second, more complex process. But like the case of accommodation, we can derive this description only by noting differences.

The first of these differences follows from a fact already noted, that people can assimilate new objects along many diverse dimensions unlike negative feedback systems which respond to only one pre-defined parameter of their environment. This flexibility makes assimilation intrinsically more complicated than negative feedback. Thermostats can neglect all properties of their environment except temperature because all other dimensions are irrelevant to the task of regulating heat. In contrast, Jonathan had to notice a broad range of properties within his environment because he could not predict the parameter of his attachment object that a new environment would bring to

mind.

But as with accommodation, the same condition that leads to complication simultaneously creates a useful simplification. Unlike the thermostat which has the capacity to compare only temperatures, Jonathan had the ability to compare objects along many dimensions. The significance of this ability was that Jonathan could keep changing the dimension along which he extended his theme, from generalizing among characters, to episodes, to television series, to media. Each time he changed his dimension, he acquired increasing intellectual power from his theme since it became applicable in a broader range of contexts. In having this flexibility, Jonathan had a distinct advantage over the rigid process of negative feedback.

Based upon the preceding analysis, I will present a two-step process which could provide the top-level of control over Jonathan's assimilation of both Bickley's theft and the wedding episode to the object of his attachment, Mork. The first step, the one that activated his tendency to assimilate, was his noting a dimension of similarity between the novel object and the object of his attachment. The second was to evaluate the novel object in terms of a theme associated with the object of attachment; for the two events in question, that theme was fictional realism.

This description of assimilation is subject to the same objection of triviality as my earlier description of accommodation, an objection answerable by the same defence. The theory may seem question-begging because it offers no solution to the greatest mystery in Jonathan's behaviour, namely how he perceived a useful similarity between the two novel objects and the object of his attachment. Again the answer is to distinguish the process of assimilation from the problem of detecting similarities. The latter is a familiar problem in Psychology, for a long time considered difficult, and beyond the scope of the present research. By reducing assimilation to this other familiar problem, my analysis constitutes a real contribution to knowledge.

The significance of the preceding analysis is that it permits us to view theme proliferation as an iterative process composed of successive acts of assimilation. Thus assimilation is a theory of the

top-level of behavioural control for proliferation stage of learning. Similarly, our earlier analysis of accommodation yielded a top-level description of a control process for the discovery stage. In the remainder of this chapter, I will propose a final control process capable of coordinating assimilation and accommodation into a unified process of adaptive learning. In advancing a mechanism for equilibration, I hope to have found a model useful for other theorists wishing to explain adaptational control.
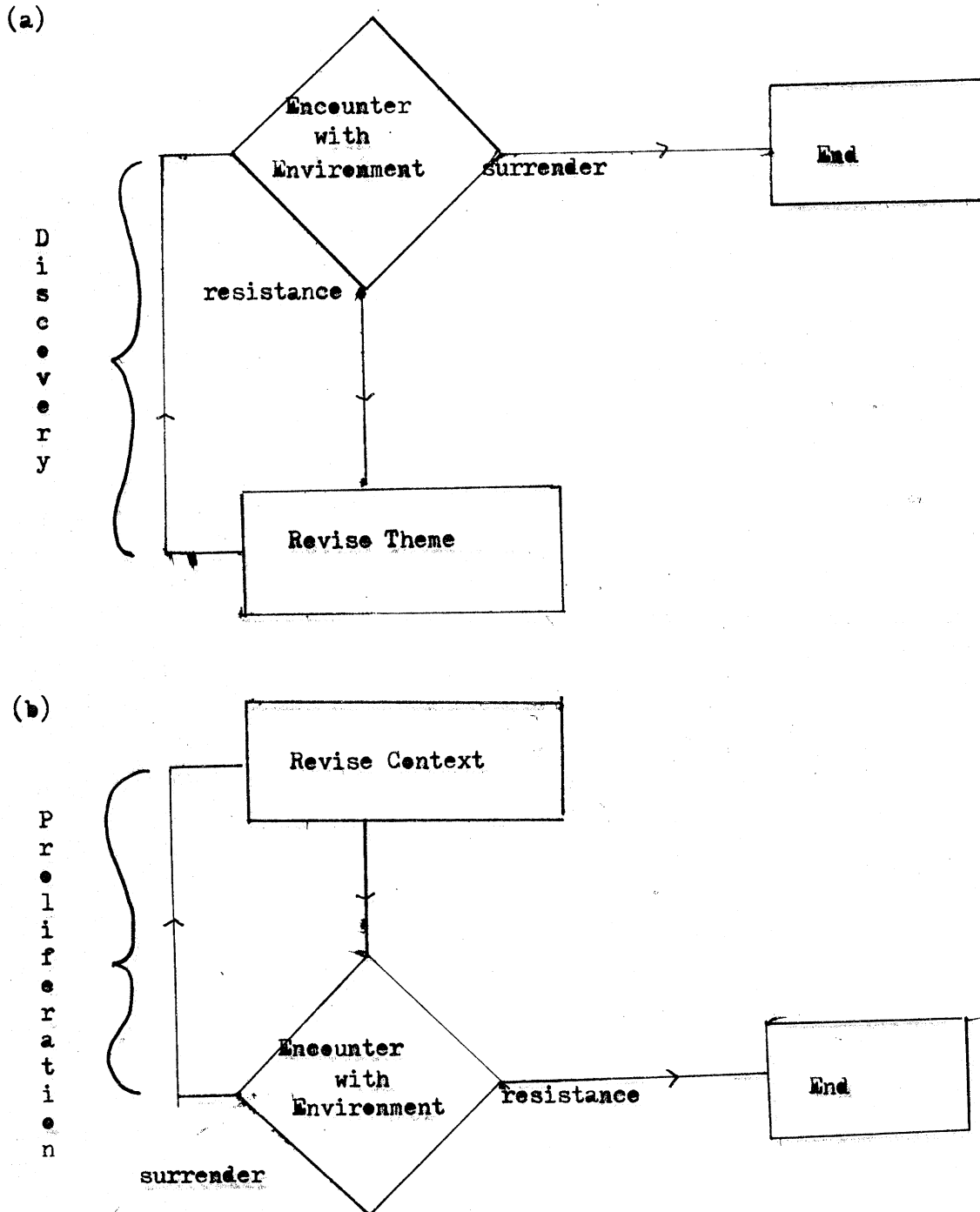
5.7 Equilibration

The analysis of discovery and proliferation, the work of the last three sections, has yielded descriptions of two high-level control processes, accommodation and assimilation. I will complete my discussion of Jonathan's and Toby's experiences by examining the interaction between these two processes, to derive an explanation of their long-term contribution to adapted learning.

The two flow charts shown in figure 5.3 provide summary representations of accommodation and assimilation. As the chart makes clear, both processes have an iterative structure. The accommodation loop is activated when an encounter with the environment, such as Jonathan explaining why Mork danced or Toby trying to synthesize purple smoke, leads to resistance; that is, a failure to produce an anticipated outcome. The two boys reacted to such resistance by revising their themes and then provoking a fresh encounter with the environment, to see if the revised theme would function more effectively. This alternation between encounter and revision continued until the resistance was overcome, at which point they exited from the accommodation loop. The effect of repeated accommodation was the discovery of new themes.

FIGURE 5.4

Flow Chart Representations of
Accommodation and Assimilation

The flow chart shown in figure 5.4 (a) represents the flow of control for accommodation. The flow chart shown in figure 5.4 (b) represents the flow of control for assimilation.

(a)

D i s c o v e r y

Encounter with Environment — surrender → End

resistance

Revise Theme

(b)

P r o l i f e r a t i o n

Revise Context

Encounter with Environment — resistance → End

surrender

On the other hand, the assimilation loop remained active as long as their environment kept surrendering to their themes; that is, as long as their themes kept proving relevant. As the spontaneous variation of their environment produced small changes in their micro-worlds, both Jonathan and Toby tried to assimilate these revised control contexts to their themes. They continued imposing their themes on newer and newer contexts until they encountered a resistance, at which point they exited from the assimilation loop. The effect of repeated assimilation was the proliferation of their themes to an increasingly borad range of contexts.

I intend now to relinquish the derivative problems of accommodation and assimilation and return to the fundamental issue with which I opened the chapter, namely the issue of learning. As I argued at the time, both Jonathan and Toby acquired new, powerful ideas as a result of their experiences in the research micro-worlds. Jonathan began to appreciate the complex relationship between fiction and reality, a relationship where fiction captures the essential facts about reality but distorts the unessential details. And Toby came to understand the usefulness of making purple smoke, a talent that helped him discover chemical reactions, study the movement of gases and improve his social status. For neither boy can the acquisition of a powerful idea be reduced to either accommodation or assimilation. While accommodation led to original ideas, these ideas were lacking in power. Like Jonathan's final judgment that Mork's dancing was exaggerated, or Toby's first success in reproducing the purple smoke, the results of accommodation were the solutions to local problems, offering new promise of being generalized to new problems of the future. Conversely, while assimilation led to powerful ideas, these ideas were lacking in originality. Like Jonathan's proliferation of fictional realism or Toby's proliferation of purple smoke, assimilation caused pre-existing ideas to be generalized, but it could not transform them into new ones. Thus to explain Jonathan's and Toby's learning, we require a mechanism that combines the advantages of accommodation and assimilation while overcoming their disadvantages. We need an explanation of how old and local ideas can become transformed into new and powerful ones. I will now argue that

Piaget's theory of equilibration provides this very mechanism.

The idea of equilibration is often, and justly, considered the most difficult of Piaget's concepts. Its difficulty however is not the product of its intrinsic complexity or confusion, as most psychologists believe, but rather of its radicalness. The scepticism of psychologists to;ward Piaget's theory can be compared to the initial reaction of physicists toward Einstein's theory of special relativity. At the beginning of the twentieth century, the picture of time as absolute was so deeply engrained in physicists' thinking that most had trouble even grasping the idea that time, in fact, is relative. Similarly, the picture of behaviour as instrumental is today so deeply engrained in psychologists' thinking that most of us have trouble even grasping the idea that some control processes are mediational.

To appreciate how fundamental is Piaget's challenge, we should keep in mind just how widely ideas of instrumental control pervade Psychology. To illustrate its influence, I will compare three theories chosen to represent opposing extremes among points of view in Psychology; these are Freud's psycho-analytic theory, Skinner's operant theory and Newell and Simon's General Problem Solver. These three are unlike each other, not only in the problems which they address but also in their methods for finding solutions. But despite these genuine and fundamental differences, ideas of instrumental control figure in all three of them. Freud interpreted neurotic symptoms as providing symbolic satisfaction of frustrated instincts; Skinner believed that organisms learn by reproducing responses that lead to positive reinforcement; and Newell and Simon pictured problem-solving procedures as means of reducing differences between a current state and a goal state. Given our habit of thinking in instrumental terms, our resistance to Piaget's theory is not surprising.

I will introduce equilibration by adapting an argument from Claude Levi-Strauss, the French anthropologist who first applied Jakobson's methods of structural linguistics to the study of social phenomena. One subject of special interest to Levi-Strauss has been the systems of classification used in traditional societies to categorize plant and animal species. These taxonomies

had caught the attention of many anthropologists because they differ so greatly from the classification systems used in Western Biology. The original contribution of Levi-Strauss was not in analyzing these systems *per se* but rather in asking a new question about them.

Before Levi-Strauss, functionalist anthropologists such as Malinowski sought to explain these taxonomies in instrumental terms. They assumed that species were classified to help serve biological needs such as nutrition. But according to Levi-Strauss (1962), these instrumental analyses invert the true direction of causality. It is not that plants are classified because they are good to eat; but rather plants are eaten because they are "good to think." In other words, classification is a natural tendency of human thought; if it leads to finding edible food, that is an effect and not a cause of classification.

My reaction to Levi-Strauss's criticism is like Jonathan's opinion of Mork's dancing, that it is slightly exaggerated but essentially right. Some behaviour genuinely is instrumental; in part, the talent of Freud, Skinner and Newell and Simon has been to discover just those psychological phenomena susceptible to instrumental analysis. But most control over human behaviour is exerted neither by goals nor motives nor reinforcers nor any other instrumental force; rather most control is exerted by natural tendencies, such as the tendency to classify studied by Levi-Strauss, or the tendencies that I have been describing, such as interest, attachment, assimilation, accommodation and equilibration.

But in rejecting instrumentalism, Levi-Strauss leaves himself open to two counter-criticisms. The first is the problem of adaptation. If Malinowski is right, it is easy to understand why behaviour so frequently is adaptive. If people classify plants because they are good to eat, then they will continue classifying them only as long as they remain good to eat. When plants stop being good to eat, then people will change their behaviour so that it better serves their needs. But if Levi-Strauss is right, it is difficult to explain why behaviour so often is adaptive. If people will continue classifying whether it be adaptive or not, they risk retaining behaviour patterns long after they serve any useful

purpose.

The second is the problem of unity. In order to carry out even a moderately ambitious project, human beings must be able to subordinate their psychological resources to selected ends. Behavioural tendencies, such as the tendency to classify, must become activated when they are needed and suppressed when they are not. If the human mind is organized instrumentally, we should expect both thought and behaviour to be unified. However, if it includes numerous independent behavioural tendencies, as Levi-Strauss suggests, then we lack a reason for expecting such unity.

While not under-estimating the seriousness of these criticisms, we must keep in mind that both objections are essentially technical rather than fundamental. They both point out problems in need of solutions rather than defects incapable of repair. It is useful to compare these two objections to Levi-Strauss's theory with the early objection I raised against trial-and-error theories. Although Levi-Strauss has no present solution to the problems of unity and adaptation, it is logically possible for both to be solved in the future. In contrast, my objection to trial-and-error theories is fundamental rather than technical. Given the experiences o;f Jonathan and Toby, we must concede that at least some instances of learning are controlled by processes other than reinforcement.

The co-ordination of assimilation and accommodation illustrates the general problems of unity and adaptation. So far, I have been picturing assimilation and accommodation as independent psychological tendencies, just as Levi-Strauss pictures classification as an independent psychological tendency. Within this framework, it is easy to appreciate the direct short-term effects of both processes; we can understand that accommodation yields novelty and assimilation leads to generality. But it is hard to see why these two processes should interact in the service of a higher-level goal, such as the generalization of novel themes; and it is even more obscure why the themes being generalized should be the adaptive ones.

It is significant that the discovery stage came first in both boys' learning and the proliferation stage only afterwards. During the early sessions, Toby and Jonathan both concentrated

their learning in accommodation, as exemplified when Toby revised his conservation of colourfulness theory during the first session, or when Jonathan refined his belief in Mork's weirdness during the first and second sessions. In contrast, during the later sessions, they relinquished accommodation in favour of assimilation. Thus they began to generalize their themes only after adapting them to the constraints of the research micro-worlds.

In order to understand the importance of this temporal order, consider the alternative case in which the proliferation stage would have preceded the discovery stage. Under those conditions, Toby and Jonathan would have proliferated their earliest themes; these would be the conservation of colourfulness theory in the case of Toby, and the concept of weirdness in the case of Jonathan. And when they eventually did discover the more sophisticated alternatives, these new themes would fail to become generalized. By comparing the observed order of stages with the hypothetical alternative, two consequences of the observed order become apparent. First it confined the lethal effects of the initial maladaptive themes; since these themes were never generalized, they failed ton contaminate thinking in more than a few local contexts. Second it amplified the constructive effects of the later well-adapted themes; since these themes did become generalized, they could help the boys to analyze a wide range of events.

Thus the significance of the observed stage order results from its adaptive and unifying effect. Because the discovery stage preceded the proliferation stage, and not vice versa, it was possible for original adaptive themes to become generalized. The experiences of Jonathan and Toby reveal processes of control more powerful than the ones that Levi-Strauss describes. In addition to their tendencies to assimilate and accommodate, Jonathan and Toby demonstrated a unifying tendency to switch from one process to the other when such alternation was adaptive. Their coordination of assimilation and accommodation demonstrates that both boys' behaviour is organized with greater complexity than a simple collection of behavioural tendencies. It reveals the influence of some mediating process causing these tendencies to become co-ordinated. The relevance of Piaget's
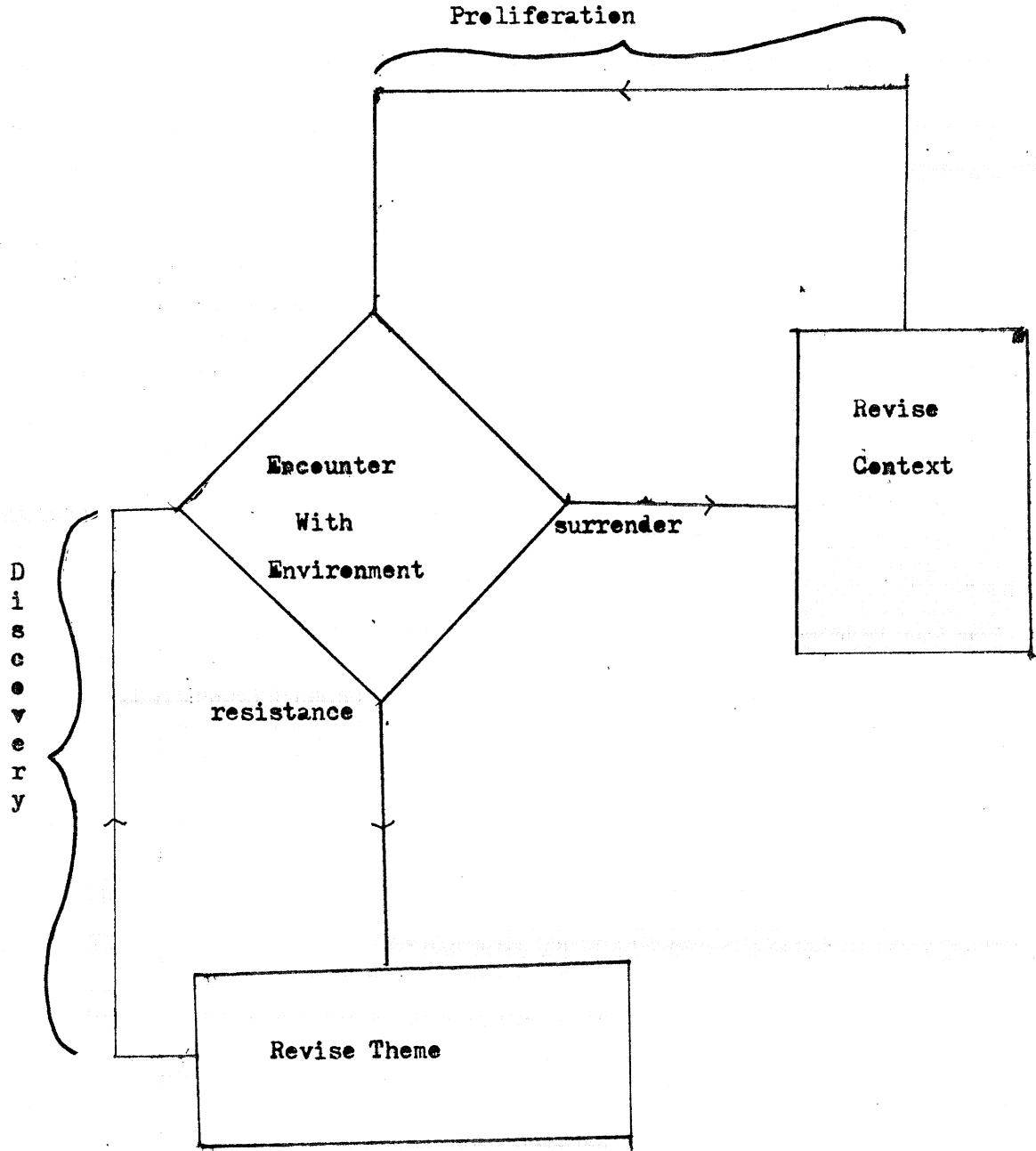
theory of equilibration is its ability to explain this process of mediation.

The flow chart shown in figure 5.5 illustrates the flow of control for equilibration. The value of this flow chart is that it preserves our earlier representation of assimilation and accommodation, presented in figure 5.4, while depicting the relationship between the two processes. As I argued earlier, the structure of both accommodation and assimilation is iterative, consisting of an encounter with the environment and a reaction to that encounter. These two iterative processes are represented in figure 5.5 by the two intersecting loops, so that the loop on the left is identical to our earlier representation of accommodation and the loop on the right is the same as our previous representation of assimilation. The difference between this flow chart and the earlier one is the replacement of the existing conditions by a process of transition from one loop to the other. The earlier diagram presented assimilation and accommodation both as processes of finite duration, which continue for an unspecified time and then stop. The present representation shows equilibration as a process of infinite duration, including periodic alternations between two-processes, assimilation and accommodation.

FIGURE 5.5

A Flow Chart Representation of Equilibration

Proliferation

Encounter

With

Environment

surrender

Revise

Context

resistance

D
i
s
c
o
v
e
r
y

Revise Theme

In portraying learning as a unified process, this picture of equilibration captures the continuity of Jonathan's and Toby's learning. Throughout the course of my analysis, I was able to describe the development of Jonathan's fictional realism theme and Toby's purple smoke theme as a continuous process of local modifications, in which the environment served to alter, rather than replace, pre-existing habits. To illustrate this pattern of continuous change, I will describe a simulation using the equilibration diagram. This simulation traces the development of Jonathan's realism theme from the concept of weirdness, from which it was derived, to its ultimate proliferation to media other than television.

During the opening session, Jonathan assimilated his weirdness theme to a wide variety of events all concerning Mork; these included some jokes that Mork told, a dinner party he organized, and his general behaviour, evaluated globally. Jonathan encountered his first resistance while analyzing the dinner party. After noticing Mindy's comment that Mork really was trying to make a good party, Jonathan accommodated for the first time, observing that Mork was in fact behaving realistically in making a dinner party. Following this observation, Jonathan never again mentioned the concept of weirdness having replaced it by the opposite concept of fictional realism.

During the second session, he assimilated a sequence of events to the fictional realism, again all of them concerning Mork, until he encountered his second resistance; this was my objection to his saying that Mork would realistically dance at a basketball game. As we have often noted, Jonathan reacted to my objection by introducing the distinction between realism and exaggeration. Following this last accommodation, Jonathan continued assimilating newer and newer contexts, never again encountering further resistance. The process of repeated assimilation led to the rapid generalization of his fictional realism theme, until it overcame the bounds of the research micro-world, assimilating experiences from the rest of his life.

This simulation shows that the difference between the discovery stage and the proliferation stage consists not in the presence or absence of assimilation but rather in the influence of

accommodation. Assimilation played a role in the discovery stage, permitting the repeated application of the weirdness theme, just as it did during the proliferation. On the other hand, accommodation ceased while the realism theme was proliferating. It is therefore possible to define the boundary between the discovery stage and the proliferation stage as the point at which accommodation stops.

But the main significance of Piaget's equilibration theory comes from the role it postulates for particular experiences in the acquisition of general principles. The relationship between the general and the particular has been a recurring theme in psychological research, arising in many diverse contexts. To explain such varied phenomena as behaviour modification (Skinner, 1953), concept acquisition (Vygotsky, 1962; Bruner et al., 1956; Winston, 1975; Rosch and Mervis, 1975), and hypothesis formation (Inhelder and Piaget, 1956; Kuhn, 1972: Osherson, 1976), psychologists have had to determine how short-term experiences can have a long-term influence. Piaget's own program of research can be seen as a microcosm of Psychology, at least of the psychological community concerned with the effect of particular experiences, because he has investigated the three main problem domains that embody this broad question. His research on infancy analyzed behavioural change; his studies of middle children considered concept acquisition; and his research on adolescence investigated hypothesis formation.

Piaget's work may be viewed as microcosm not only in the empirical questions it has addressed but also in the theoretical answers in has given. Like Psychology as a whole, Piaget has been torn between opposing interpretations of environmental influence. Some of the time, he adopts an instrumentalist stance from which he sees the environment as exerting a negative influence, testing pre-existing hypotheses. Other times, he adopts an empiricist stance from which he sees the environment as exerting a positive influence, embodying positive principle capable of being abstracted. A central controlling principle in Piaget's theorizing has been to overcome the conflict in his own mind between instrumentalism and empiricism. It led to development of his most

tradition-bound theory, the theory of stages, as well as his most revolutionary theory, the theory of equilibration.

As Seymour Papert (1980) has pointed out, "the Piaget of the stage theory is essentially conservative, almost reactionary, in emphasizing what children cannot do." By picturing psychological development as an inevitable passage through a fixed sequence of stages, the conservative Piaget endorses the dismissal of experience as having a minimal effect on intellectual growth. In contrast the Piaget of equilibration is essentially radical in emphasizing that experience can change not only the content but also the structure of thinking. Papert calls the equilibration theorist, "a revolutionary Piaget, one whose epistemological ideas might expand known bounds of the human mind."

Piaget's study of hypothesis formation, published in 1956 with Barbel Inhelder, reflects a typical concern of the conservative Piaget. The question unifying this book asks, how do experiences, as represented by scientific experiments, lead children to acquire valid scientific knowledge? On the other hand, Piaget's study of the origin of intelligence, published in 1935, reflects a typical concern of the revolutionary Piaget. The question unifying this earlier book asks, how do experiences transform inherited cognitive and behavioural patterns, making them increasingly well adapted to the environment?

As the experiences of Toby and Jonathan demonstrate, knowledge can become well adapted without becoming valid. Consider Toby's hypothesis that sulfur plus sodium iodate must be heated in order to synthesize purple smoke. Although this hypothesis was useful for Toby, it remains nonetheless technically false, since the sodium iodate would produce purple smoke even in the absence of sulfur. For Jonathan as well, we have reason to question the validity of his judgments. It is more difficult to evaluate the soundness of Jonathan's opinions than it was for Toby, since we cannot compare them with any established scientific theory. But one basis for doubting Jonathan's judgments was his regular practice of doubting himself. Three times during the study, he altered his

evaluation of Mork's dancing from considering it realistic to unrealistic or vice versa. The volatility reflected by this and other scenarios places in question the truth of at least a percentage of Jonathan's opinions.

What they did acquire was complexity and power. The themes of purple smoke and fictional realism not only were subtler than their precursors but also were more useful. This fact explains why the present research helped articulate a theory of equilibration. Since Piaget developed his theory to explain adaptation, it follows that the theory should be relevant to a study of children in the process of adapting.

Figure 5.5 summarizes the principal finding from this study that particular experiences contributed to the acquisition of knowledge by means of the reactions that they elicited from Jonathan and Toby. They led to the discovery of new themes when they caused a reaction of accommodation; and they led existing themes to become proliferated when they caused a reaction of assimilation. Which of these reactions occurred depended on neither mental nor environmental control exclusively, but rather on the interaction between them. If micro-world and theme resisted one another, the boys reacted by accommodating the theme. On the other hand, if the micro-world surrendered to the theme, they reacted by assimilating a new event within the micro-world.

6. Leonardo

There's little difference between one person and another but what difference there is is very important.

--William James--

In earlier chapters, I have tried to present an overall picture of what children learn in a micro-world. This goal of comprehensiveness affected my analysis of Jonathan in the *Mork and Mindy* World and of Toby in the Chemicals World. In both of these discussions, I wanted to describe every important theme which dominated their learning, and the transition points when these themes acquired their importance.

The present chapter will take a perspective which is both broader and at the same time more focused. First I will report events from a broad range of settings. Rather than limiting myself to one experimentally defined micro-world, I will describe experiences in Leonardo's home, in his classroom and in both of my research settings. Second I will focus on just one lesson which Leonardo learned. This lesson is especially instructive for both psychologists and teachers because it illustrates how greatly the effect of one's teaching may diverge from one's goals. This was a lesson I neither expected to teach nor enjoyed learningD.

The last time I saw Leonardo was on December 18, 1979. It was 2:20 in the afternoon, the end of the school day, and I was meeting him for our eleventh session, the fifth in the *Mork and Mindy* world. The session never took place. When I saw Leonardo, I asked him, "Are you ready?"

"I'm not going. I told you last time I didn't want to come any more."

"You want to end the research?"

"Yes."

He had never told me before that he would end the study. But his decision was not

particularly surprising. As the research progressed, it became increasingly clear to me and to Leonardo that he was not having a good time. Each week, he seemed slightly less enthusiastic than the last session. A natural consequence of his alienation would be to quit.

I propose to examine how Leonardo learned that my research was no fun for him. The object of this lesson was not a chemical from the chemicals world nor a character from *Mork and Mindy* but Leonardo himself. As with Jonathan and Toby, Leonardo's learning focused on a particular theme which I will call 'the resistance theme.' Just as Jonathan was interested in assessing Mork's realism, and Toby was interested in pouring his purple smoke, Leonardo became interested in avoiding my research. Throughout the research, this theme came more and more to dominate Leonardo's actions.

It is tempting to see alienation as the result of unending failure. You might suppose that Leonardo experienced an uninterrupted sequence of frustrating, punishing episodes. The truth however was not so one-sided. The vast majority of the time, Leonardo appeared as interested as Jonathan or Toby. Like the other two boys, he seemed absorbed while watching *Mork and Mindy* and excited when making discoveries about chemicals. Although they eventually proved very significant, Leonardo's expressions of resistance were rare isolated events.

I want to describe one episode totally unrelated to the resistance theme. This episode was not at all special and that indeed is the reason for mentioning it. It shows Leonardo the way he usually appeared, as an eager and effective learner.

The episode began late in the second session and continued into the third. Leonardo had just heated a test tube containing water, sulfur, sodium iodate and ferric oxide. The contents of the test tube had overflowed and Leonardo had wiped up the spill. Then Leonardo put the test tube into a beaker of cold water to cool off.

Leonardo looked at his test tube. "I think I just made ink. It looks like ink. I'm sure that'll write."

Leonardo found a stick and piece of blank paper. He dipped the stick into his mixture and wrote his name on the paper as if he were using a fountain pen and ink well.

Then he mixed green food colouring with water and sodium iodate in a fresh test tube. He announced that this second mixture was 'green ink.' He said "this ink isn't as good as the black ink. The colour is too dark."

Using the same pen and paper, he wrote his first name in green ink just as he had previously written his first and last names in black ink.

At Leonardo's request, we stored his black ink for the next session. When we met again, Leonardo immediately began inspecting the remaining mixture. "I should have wrote down what the ingredients for this was. Do you remember what the ingredients was?"

I answered honestly, "I don't remember at all."

"All I know is it seemed like I made all of them mixed together."

Leonardo placed the test tube of his ink into an empty beaker. He picked up a clean test tube and then opened the jar of sulfur. "This, I'll try these three. I'll put this inside. First water."

He poured some water into his fresh test tube. "How much should I put in? Oops. I'm going to pour a little bit in case that's too much."

He poured a little out. "I'm going to pour a little bit out in case that's too less."

Leonardo added a little water and some sulfur. "Now I've done this.

"I think that's enough."

"I think I remember it was..." He opened the sodium iodate and added it to the mixture. "There. Now the iron whatever-it's-called."

He meant the ferric oxide. From his knowledge of Italian, Leonardo had deduced that 'ferric' meant 'iron'. He added ferric oxide to the mixture. Then he put a cork into the test tube; he shook it; and he removed the cork. Next Leonardo put on his safety goggles, turned on the bunsen burner and held his test tube in a clamp over the flame. "Should I put it a little bit higher?"

"I think that's certainly high enough."

"I can hear the stuff inside evaporating."

"What sound does it make when it evaporates?"

"Like it's boiling. I know what sound boiling makes."

Leonardo turned off the heat and put the test tube into a beaker of water. "Now it's cooled off. Do you have the stick? Goody. Checking if this could be used as ink. I'm going to write down the ingredients. I don't think this is going to work."

Leonardo tried to write with the fresh 'ink'. "It works great! Now I'm writing down what I've done, what I used. Now I have to check if this and this are the same."

He put the stick into the mixture from last week and wrote the letter 'O'. Then he did the same with the new mixture. "Ya. I think I'll pour this into this." Through a funnel, Leonardo poured the new mixture into the previous week's test tube of ink. The new mixture became blended with the old one.

You should note that Leonardo's new mixture had exactly the same chemical composition as his old. Even though he had produced the ink only once during the previous session, and even though a week had elapsed in the meantime, Leonardo had remembered perfectly the formula for his ink.

"Now I need to write on this paper the ingredients of ink. Can I have a pen? How do you spell 'ingredients'?

He had begun to write 'i-n' on a sheet of blank paper. "You've already started: i-n-g-r-e-d-i-e-n-t-s."

"I'm writing fast. Which one did I put in first, this or this?" He pointed to the sulfur and the sodium iodate. "I think I put in this one. Is this the yellow stuff? I put the yellow stuff in first. Ya. First I put water."

"I forget how to write words. I haven't been writing for a long time. How do you write

'water'?"

He wrote a 'w'. "You already started right."

"a. w-e-a."

"w-a." I corrected him.

"t-e-r. What's this called again?"

"Sulfur."

He wrote 'sulfur'. "Can I write 'iron' in Italian? 'Cause I know how to write my last name 'cause my last name is Iron."

I pointed to the ferric oxide. "Look at the jar. Isn't that almost your last name?"

"Yes except for the 'c'. That means 'iron' in Italian. I bet you won't believe this. My father's parents and their last name is 'Ferri' that means 'iron'. And my mother's mother's and father's last name is Iron. They have the same last name. My mother's father, my grandfather, he's English; he works on trains; he builds trains about that big that go by coal. He's working on one about that big that's strong enough to carry twelve people. Not carry, I mean strong enough like my father and you. Which way should I write 'iron'? I'm not sure how to write 'iron'. I'll do it the Italian way."
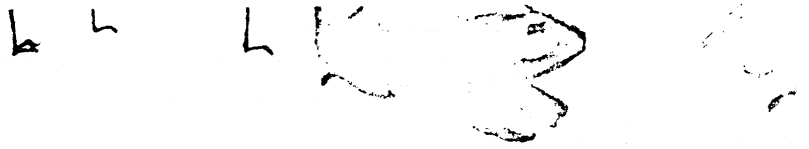
Leonardo finished the recipe which appears in figure 6.1. Then he searched through some art supplies stored in our research room until he retrieved a quill pen and a bottle of india ink. "This is the regular one we use all the time. India ink. That's the kind we use. Good."

Figure 6.1

Leonardo's Recipe for "Ink"

The Ingredients of ink

Water. Sulfar. Sodium iodate. Ferri oxide.
Put all ingredients in Test Tub Then put Test Tub under Fir
A minute. Then Put Test Tub in water For colling oof.

He inspected the bottle of India ink and then the test tube of his own ink. "They're both the same. Sort of. I don't know what the difference is. I think one's darker than the other. I think. I'm not sure. They both write the same. Oh oh, I forgot one thing. I'm not sure if they're the same."

Leonardo wrote a series of L's with the quill pen; first he used the india ink and then his own ink. He inspected his writing. Finally he concluded, "No I don't see a bit of difference. I'm not sure. It doesn't seem like there's a bit of difference. Don't seem like any difference. I guess I made ink. What should I do now?"

Suppose we compared Leonardo's discovery of his ink with Toby's discovery of purple smoke. There are admittedly important differences between the two incidents. Leonardo showed a great interest in the names of the chemicals, an interest which Toby lacked. Toby was interested in varying the ingredients of his mixture, an interest which Leonardo lacked. But these differences are differences of detail. If we asked, which boy will become attached to his discovery and which one will withdraw prematurely from the research, on the basis of their respective experience with the chemicals, I believe, no observer could know. In fact Leonardo's initial encounter with his ink was intellectually just as productive and emotionally just as involving as Toby's initial encounter with purple smoke.

Consider three important similarities between the two events. First both incidents began with the discovery of a new product, either ink or purple smoke. At the point of discovery, both children showed unmistakable signs of excitement. They continued to act excited as they experimented with their discovery. Second both children invented novel uses for their product. Toby learned that he could pour his smoke, stain objects yellow and impress his friends. Leonardo learned that he could write with his ink, change its colour and compare it with India ink. Third both Leonardo and Toby sustained a fluent interaction with the chemicals. They seemed to produce new ideas so quickly that they were never at a loss for new experiments. They worked steadily and inventively.

Why then did Leonardo eventually become alienated and Toby become attached? To answer this question, we should keep in mind that alienation is not simply the absence of interest but rather it is an active form of resentment. People can become just as emotionally involved with the objects of their alienation as with the objects of their attachment. The difference is that attachment draws one's attention toward its object but alienation drives this attention away. I propose now to describe the rise of this alienation system.

Leonardo's question "what should I do now" underscores the difference between his feelings and Toby's. In the most explicit terms, the uttrance reminds us that Leonardo did not know what to do. Similarly, his comment about "next year" reflects his detachment from this year. If he were as involved in the present micro-world as were Toby and Jonathan, he would have had no time to think about next year.

It is interesting that the dominant theme for all three boys first appeared in the opening session. For Jonathan, it introduced the idea of fictional realism; for Toby, that of mixing sodium iodate and sulfur; and for Leonardo resistance. In fact, the first sign of resistance preceded even the beginning of the first session.

The conversation took place in Leonardo's classroom on the day when I first met him. Leonardo knew something about my study because I had sent a description of it to every student in his school. On the basis of this description, Leonardo and his parents had expressed interest in the research.

My letter had said, "The first half of the experiment will deal with the subject of combustion. You will have the chance to figure out why things burn. (At that point, the fire and not the chemicals seemed like the most important component of the chemicals world.). . . . During the second half, we will study the television series *Mork and Mindy*." From this letter, Leonardo gained an impression of the research which I had not intended. He thought he was going to learn about cars and telephones. When I said he was going to learn about fire and television, he asked "Why did you

say in the letter that it was going to be about cars and telephones?"

I answered that the letter did not mention cars and telephones. Leonardo protested, "I know it did because I read the letter."

At that point, I told him that he could work with me if he was interested in fire and television. But if he was not, he did not have to participate. "Are you interested in what makes things burn?"

"That's easy. You just have to get wood, or some kind of plastic or wax."

It is easy to speculate why Leonardo was so committed to his interpretation of my letter. Perhaps he did not want to admit the unreliability of his still rudimentary knowledge of reading. Like most eight year olds, Leonardo had not yet become fluent in the written language. Or maybe he considered the source of his interpretation to be his father (whom he dearly respects). But the cause of Leonardo's error is less important to us than its effect. The effect was that Leonardo entered the chemicals world wishing he were in a different place. That wish caused Leonardo to protest against the content of the research.

In the chemicals micro-world, the resistance theme never dominated Leonardo's actions. It appeared as an undercurrent surfacing at odd moments and then disappearing. A far more important theme was the 'discovery theme'. During his six sessions with the chemicals, 'ink' was not the only household product which Leonardo discovered. One week, he made 'honey' (by heating a sugar and water solution); another, he made a 'crayon'.

Ironically, his resistance began to escalate in the first *Mork and Mindy* session, the meeting which Leonardo "could not wait" to happen. For that session, I showed Leonardo a video-tape which had been especially important to Jonathan. It was the episode when Mindy had sent Mork to a basketball game so that she could be alone with her date. Mork had returned home early and embarrassed Mindy. To save her further embarrassment, Mork ran away from home, eventually discovering a lunatic group called 'the friends of Venus'.

While watching the program, Leonardo gave the appearance of being totally involved. He gazed intently at the television, apparently unaware of people wandering in and out of the room or of background noise. He laughed at the jokes. I had every impression that he was enjoying the show.

As soon as the program ended, Leonardo commented, "It was strange."

The comment at the time did not seem particularly odd. During his first session, Jonathan too had remarked on Mork's strangeness. But unlike Jonathan, Leonardo was not making a neutral observation. Leonardo's comment was a gentle complaint.

"How was it strange?"

"It didn't show him going up to his room."

Unlike Jonathan Leonardo failed to see the strangeness as a source of pleasure but rather of uneasiness. He expected to see Mork slide *up* the stairs to his room (as Mork sometimes did) and was disappointed when his expectation was never realised.

"It didn't show him even when he was going up to his room."

"Why should they?"

"Most of the time, they show him going up to his room most of the time. He just goes up like the staircase, comes down then he just goes up. Now what should we do?"

This question had become familiar in the chemicals world. When Leonardo had become distracted from the experiment at hand, he often asked, "What should we do?" This question had become a reliable sign of non-involvement.

"Tell me about the show. Did you like it?"

"It was strange. What show are you talking about? The one we just saw?"

"Ya."

"What should I say? What should I tell you?"

In the Chemicals World, Leonardo's requests for guidance were isolated events. He was usually too involved in his discoveries to need any help from me. But now Leonardo was becoming

more demanding. Instead of single isolated requests, Leonardo was asking me over and over again to tell him what to do. I tried to oblige him.

"Did you like it?"

"Ya sort of."

While watching the show, Leonardo appeared to enjoy it as much as Jonathan or Toby. But now he was expressing at best mild approval. It is possible of course that his behavior during the program was misleading, that he had laughed heartily at mediocre jokes. Neither however should we ignore a second possibility: that his ambivolence was directed not toward the program but toward something else. According to this second interpretation, he was expressing a genuine feeling but suppressing its true object.

"Sort of?", I asked.

"Ya."

"You didn't really like it though?"

"No."

"What did you dislike about it?"

"Like when he asked about the shot; I didn't like that part."

"When he shot down the albums?"

"Ya."

"You didn't like that."

"I didn't like that."

"Why not?"

"'Cause it costs a lot of money to get those albums."

"So was he wasting money by shooting down the albums?"

"Ya."

"Couldn't you just pick them up again?"

"Yes, but I bet they'd be all broken."

Without having seen the episode, it is difficult to appreciate how truly bizarre this conversation was. If one incident had coloured his reaction to the program so much, you would expect it to be a very important incident. It might be a long incident, occupying a large proportion of the program's time. Or it might have served a crucial function in the plot. But this record album incident was hardly important. It was a brief connecting incident, introduced merely to advance the plot.

According to Leonardo, he had disliked the entire program because he disliked the cost of replacing some supposedly broken records. In other words, he was claiming to dislike the program on the basis of a misinterpretation of a minor incident.

"What part did you like?"

"The end."

"Why did you like the end?"

"When he was in his real suit. 'Cause um the only part I really liked about it was when he was in his real suit."

At the end of the program, Mork wore a special costume intended to represent a spacesuit. The rest of the time, he wore conventional American clothes. It is possible that this change of costume was very important to Leonardo. Yet we should not overlook an alternative interpretation. When people claim to like the end of a story, they are not always intending praise. To say the end was good can be a clever way of meaning that the story was bad. It can suggest the story was so bad that the best part came when it finally ended.

[For comments such as the last, the question arises: which interpretation should we prefer, the obvious literal one or the subtler symbolic meaning? Of course the more we read into a statement, the greater the risk that we perceive unintended meanings. Nevertheless it is logically possible for people to mean more than they say. Therefore, we must keep our minds open to possible subtleties.

In taking a non-literal view of Leonardo's language, a reasonable procedure would be to follow the practice of philosophers of language. Many

semanticists, most notably Ludwig Wittgenstein (1953), see the meaning of a statement not in the words themselves but in their effect on the interlocutor. They see conversations as language games. Each utterance is a move in the game, designed in some way to advance the interests of the speaker.

So is it possible to interpret Leonardo's statements as moves in a game? Is there some constant function which every utterance seems to serve? The answer is yes. That function is to convey Leonardo's unhappiness.]

Throughout this exchange, Leonardo's every comment reinforces the same effect. He began by saying that he "sort-of" liked the episode, a reaction as bland as possible short of total indifference. He continued by answering my questions tersely and concisely, volunteering no information beyond the absolute minimum. Then repeatedly, he demanded that I tell him what to discuss next. Finally, he identified the most minor incidental events as his favourite parts of the program. The cumulative effect of these many acts of resistance was to underscore Leonardo's dissatisfaction with the research. Over and over again, Leonardo's and my attention were distracted away from the subject of *Mork and Mindy* and onto the discomfort which Leonardo felt.

There is a difference between this instance of resistance and the events in the chemicals world. In the chemicals world, the resistance theme was a minor one; it revealed itself only rarely in Leonardo's actions. But now it suddenly came to dominate. Every utterance became an act of resistance. This transformation resembled a similar development with Jonathan and Toby. For both boys, a time came when previously marginal themes became the focus of their attention. After his second session, the theme of fictional realism came to dominate Jonathan's thinking. Similarly, between the second and fifth sessions, the theme of pouring smoke became dominant for Toby. For both Jonathan and Toby, this sudden prolifferation of a new theme resulted from the same cause. During the same session as they started generalising their theme, they simultaneously showed the first symptoms of becoming attached.

However, unlike my other subjects, Leonardo's behaviour reflected an emotion quite different from attachment. Whereas Jonathan and Toby would often praise the objects of their

attachment, Leonardo would instead reproach *Mork and Mindy*. While the first two boys would confess feelings attached, Leonardo would admit feeling oppressed. While they continued to work with the research materials, even outside of the experimental sessions, he tried to avoid thinking about questions from the research, to the point that he eventually began missing sessions. In short, unlike Jonathan and Toby whose feelings brought them closer and closer to the research, Leonardo's emotional reaction drove him farther and farther away. In contrast to the other boys' reaction of becoming attached, Leonardo's response was to become alienated.

Two weeks after the first *Mork and Mindy* session, as usual, I met Leonardo in his classroom at the end of the school day. I asked him if he was ready to come to M.I.T. He told me that he thought we were supposed to meet not that day--it was Tuesday--but the following day, Wednesday. He said that he could not come because he had to play with some friends. He said though that he wanted to meet the next day. It seemed strange that he forgot the day of our sessions. Our choice of Tuesday had been primarily to suit his convenience (and his teacher) rather than me. But I had no reason at the time to doubt that it was an honest mistake. Since I did not want to interrupt Leonardo's soccer game, I agreed to come back the following day.

The next day, Wednesday, Leonardo and I watched our second episode of *Mork and Mindy*. Leonardo claimed to like this episode more than the first one. "I thought it was better than last time. Last week it wasn't so exciting and there wasn't all the stuff like that."

Leonardo's favourite incident was "when the whole place fell down." He explained, "The part I liked was when they got to the cabin. The cabin with all the walls fell down. And the bed fell down and the table fell down. And Exedor came down with their jeep."

I asked if any other funny things happened. "Ya there was the part when he fell down the cliff. That was funny."

I asked Leonardo if, this week, he liked the part at the end.

"Yes."

"What did he do then?"

"He was talking about a new word. About two um ah...

"Different ideas?"

"Ya."

"Like what?"

"Like well he said like these. I didn't really get this one. Like 'run'. You run a store or something like that. And you run down the street. And 'buck'. A dollar and the other one."

Leonardo seemed to have understood the epilogue quite well. Mork had showed how the same word can have different meanings. The words he used were 'run' and 'buck'. Although he did not know every sense of these words, Leonardo understood the main point of the monologue. But his failure to explain all the details upset Leonardo.

"Oh and plus another. No I don't know another. I just made a mistake."

Leonardo now was near tears. "What did you think he might have said?"

"I thought he done something else, he said something else. I don't think he did. I'll just think a little bit. I just thought but I forgot what if it was something."

A few minutes later, I asked Leonardo, "Do you want to see a part of the program again?"

"I don't feel like watching any more TV."

At the beginning of the session, Leonardo seemed ready for a productive conversation. Although he could not honestly admit to liking the program, he could and did express some approval. At least, he could confess liking it more than last time. The previous day I had compromised with him in agreeing to postpone our session by one day. In return, he now seemed willing to give my interview a chance. But good will was not enough to ensure a smooth interview. When Leonardo tried to explain the epilogue, he became frustrated. He realised that he had not completely understood Mork at the time. For Leonardo, this confrontation with his own ignorance was profoundly upsetting, making him nearly break into tears.

His failure to explain the meanings of 'run' and 'buck' undermined Leonardo's will to co-operate. For the remainder of the session, he resisted my questions just like the previous week. I finally asked him, "Is there anything more you want to say about the program?"

"No."

Then I took him home.

The next week, I arrived in Leonardo's classroom about five minutes after school had ended. I was surprised to find that Leonardo had already left. His teacher was also surprised that Leonardo had not waited for me. She explained to me that the research was very important to Leonardo. His family was going through a difficult period; there was a lot of tension between his parents. My research was one of the few rewarding experiences in his life. She knew how much he looked forward to seeing me.

The next day, I telephoned the school to find out why Leonardo had not waited. He said that he did not think we were meeting on Tuesday but on Wednesday. He offered though to work with me that afternoon after school. I agreed. But when I arrived at the school, Leonardo had changed his mind. He had an important soccer game which he did not want to miss. I reminded him that he had promised to work in the *Mork and Mindy* world. We eventually reached an agreement. I would meet him at his home after his soccer game had ended and we could then work at the research.

I arrived at Leonardo's home a few minutes before him. His parents invited me in and during the ensuing discussion, his father confirmed the story Leonardo had told me about the family television. During one Chemical Worlds session, Leonardo explained to me, "my father threw the television through the window because my sister was watching television and she never stopped." Now his father recalled that he had thrown the family television through a second story window. In retrospect, he was glad to be rid of the television. He felt that now the family had more opportunities for relaxed conversation.

When Leonardo arrived home, his father told him some bad news. During the day, one of the family dogs had killed Leonardo's pet rooster. This was quite a blow for Leonardo who had been very attached to the rooster. Since he still wanted to hold the research session, I then drove Leonardo to the laboratory at M.I.T. where the video-tape equipment was kept. The dense rush hour traffic made our trip slow so that Leonardo's delinquent dog, the rooster's assailant, was able to keep pace with my car. When we reached M.I.T., Leonardo asked if the dog could come up to the laboratory.

The presence of his dog seemed to make Leonardo more comfortable than he had in previous weeks. Of all the sessions Leonardo spent in the *Mork and Mindy* world, this was the only time he showed no resistance at all.

In our discussion after the episode, I asked Leonardo for descriptions of various incidents. He seemed quite comfortable answering my questions. Leonardo thought that a funny part came when Mork was dictating a letter to superman.

"Ya just the beginning. Oh ya I remember that was when he said to the lady; he pretends that there's a letter there and she writes the letter. He pretended that there was a lady like a secretary right next to him to write the letter and she said; oh I forget what she said."

I replayed the sequence for Leonardo.

Mork: Miss Smith, take this dictation.
Mork (in falsetto voice): No way.
Mork: Alright I'll do it myself.

That's what I liked. When he said Miss. . .I forget her name."

"Miss Smith take this dictation."

"No way," Leonardo mimicked in a falsetto voice. "That's what I liked. 'Cause then I'll do it myself."

The sequence continued.

Mork: Everyone knows that Krypton is the Miami Beach of the
universe. Ding.

You're a dry turkey in red booties. Ding.

"I liked that. 'You're a dry turkey in red booties'. That's a good insult."

The following week there again was a problem when I came to fetch Leonardo. That day was his mother's birthday. He said that he wanted to come to the research session but his father had told him to go home right after school to prepare the birthday party. He did not know what he should do. So on our way to M.I.T., Leonardo and I went to the nearby construction site where his father was working. Leonardo explained to his father the conflict between coming to the research and preparing the party. Then he asked his father what he should do.

By this time, I suspected that Leonardo's unhappiness with the research might be irrevocable. Not only had he missed two out of the last four sessions but also he had appeared distinctly uncomfortable during the sessions which he attended. Instead of Leonardo continuing to miss every other session, I wanted him to know that he had the option of withdrawing from the study. So I reminded Leonardo that he could end the research whenever he wanted. He was not forced to continue.

Leonardo's father asked him if he had missed two sessions. Leonardo nodded. His father said that he should keep an agreement if he made one. He should act like a man. Leonardo knew how angry he was when someone made an appointment with him and then never came.

Leonardo asked me how many sessions were left anyway. I answered three. His father noted that three was not very much. Leonardo said that he wanted to finish if it was only three. Then his father asked if it would be okay if he missed my session that day because it was his mother's birthday. I answered that it was. His father asked me for the dates of the remaining sessions. I looked at his calendar to find the dates of my free Tuesday afternoons. When I found them, he noted each date in the calendar. He promised to make sure that Leonardo came on all three days.

Two weeks later, Leonardo came for the session which proved to be his last. When I met him at school, he seemed nervous. He was not sure that he wanted to come with me. I told him that it was his choice. I added that he could leave at any point in the middle of the session, if he wanted. Leonardo agreed to go to M.I.T. as long as he could end the session whenever he wanted.

As usual, Leonardo appeared involved in the program while he was watching. But during the commercials, he complained.

At the first commercial, he grumbled, "this is getting a little boring."

"Do you want to leave?" I asked.

"No I think I want to stay and see what happens."

During the second commercial he demanded, "That it?"

"Do you want to see the very last part?" I replied.

"Ya."

When the program ended, I asked, "Do you want to talk about the show?"

"It started to get boring but I liked the beginning. Ya. It was all boring. Except the end. The end was a little bit better."

I asked him, "what thing at the end was good?"

"I don't know how to explain."

I made a few guesses about what Leonardo might have liked at the end, but my guesses were all wrong. I had noticed that Leonardo had been laughing during a sequence when Mork had acted like a chicken. I asked him, "Do you remember the time when Mork was acting like a chicken?"

"Ya."

"Was that good?"

"Ya a bit."

I tried another tactic. "What was the worst part of the show?"

"In the beginning when it just started."

I asked, "What was really bad about it?"

"Everything."

I mentioned a series of events and characters. Leonardo thought that every one of them was bad. I made one final attempt at conversation. "Everything was bad but it was better at the end when Bickley came in with the dog?"

"Ya."

"Would you mind if I played that scene over again?"

"Yes and no."

"What do you mean?"

"I don't really want to do it and I think you want to do it."

"I do. But if you really don't want to, then I'll go along with what you want."

"I want to go home now."

"Do you ever want to come back again?"

"I'll come back for one more."

From his behaviour during the program, it was difficult to believe that he had hated it that much. He had seemed as absorbed as ever in the episode. Not only had he had laughed at many of the jokes but, in fact, every time I asked if he wanted to leave, he always answered that he would wait until the episode had ended. The purpose of his complaints therefore could not have been to express his true feelings toward *Mork and Mindy*. He was communicating instead his own agitation.

That "one more" session never took place. When I met Leonardo on the appointed day, he refused to come with me, insisting that he had told me he would no longer continue.

It seems clear that Leonardo's alienation resulted in part from his never becoming very interested in either micro-world. The success of Jonathan's and Toby's learning depended ultimately on the ability of the micro-worlds to support the style of thinking which they already enjoyed. The

Mork and Mindy World captured Jonathan's interest by encouraging his habit of introspecting just as the Chemicals World attracted Toby's interest by allowing him to tinker. But clearly, the Chemicals World and especially the *Mork and Mindy* World were the wrong place for Leonardo. Instead of encouraging his his natural style of learning both settings left him bored and uncomfortable. The resulting frustration instigated his pattern of resistance.

During the final sessions, Leonardo's resistance theme proliferated just as systematically as the themes which dominated Jonathan's and Toby's learning. After appearing in response to a single line in my introductory letter, his resistance became generalized to larger and larger contexts. His resistance next expressed itself in response to a specific series of experiments in the Chemicals World, then to entire sessions in the *Mork and Mindy* World, and finally to the research as a whole. Thus Leonardo's experience provides an ironic twist of the same process which produced such successful learning for Jonathan and Toby. As a result of our ten sessions together, Leonardo learned that he disliked my research and wanted it to end.

The important difference between Jonathan's and Toby's learning, on the one hand, and Leonardo's, on the other, lay not in the process itself, but in its effects. In the long run, one may reasonably hope that the powerful ideas learned by Jonathan and Toby would serve some useful purpose; but a similar hope is not tenable in the case of Leonardo because he learned no powerful ideas. Collectively, the experience of these three children reveals the precarious path followed by natural learning. Learning advances no more smoothly or uniformly than any other evolutionary process toward increasing adaptation. The extent of its success depends on our aquiring an enormous amount of knowledge so that later experience can separate the good from the bad.

7. Appendix 1

This appendix contains a list of the laboratory chemicals used in the study. As long as normal safety precautions are taken, none of these chemicals pose a danger to the user (Sax, 1975; Windholz, 1976). During all research sessions, I kept a jar of graphite powder and a glass of water at hand. Although the risk of fire was extremely small, standard precautions must include the capacity to extinguish immediately any uncontrolled flame. Furthermore, no child was permitted to heat a chemical without wearing protective goggles. These are the chemicals:

Cuprous Oxide

Ferric Oxide

Graphite Powder

Lead Metal

Magnesium Metal

Phenolphthalein

Sodium Iodate

Sulfur

8. Reference Notes

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