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Development of Musical Intelligence II: Children's Representation of Pitch Relations

by

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The work reported here is an outgrowth of studies in the development of musical intelligence and learning that have been underway for about four years. Beginning as one of the activities in the LOGO Lab (a part of the MIT Artificial Intelligence Laboratory) the research has expanded to include more theoretical work in the MIT Division for Study and Research in Education.

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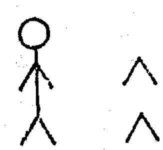
I. INTRODUCTION

The work reported here is an outgrowth of studies in the development of musical intelligence and learning that have been underway for about four years. Beginning as one of the activities in the LOGO Lab (a part of the MIT Artificial Intelligence Laboratory) the research has expanded to include more theoretical work in the MIT Division for Study and Research in Education. Work in the LOGO Lab has focused on the development of new educational technology for learning and teaching music within the context of the general LOGO "pholosophy" (Papert, 1973, 1972). In the DSRE the research has focused on the development of musical intelligence--its nature, growth and relations to other aspects of cognitive development (Bamberger, 1976a, 1975, 1976b). There has been a close interaction between these two foci, the technology providing tools for the research, the research providing a base on which to build new technology for teaching and learning.

Drawing heavily on theories of cognitive development (Piaget, Bruner, Vygotsky), linguistic and psycholinguistic theory (Chomsky, Sinclair, Fodor, Bever) and artificial intelligence-information processing models (Simon, Norman, Winograd, Minsky, Papert), I argue that basic cognitive skills underlying most human activity rest ultimately on the individual's reservoir of internal strategies of representation. I take this to mean those processes through which an individual constructs (makes sense of, finds partiuclar coherence in) and thus responds to the sensory phenomena he confronts in the world around him. Thus the particular understanding and response to an initial stream of sensory data--a tune, a spoken sentence, a line of text, a visual scene--will be mediated by the individual's internal strategies for transforming (encoding/decoding) this mass of sensory data into "meaning". These will include, for example, strategies for selecting salient features, for determining 'same' and 'different', for distinguishing and aggregating ('chunking') elements and for building and coordinating relations among these aggregates.

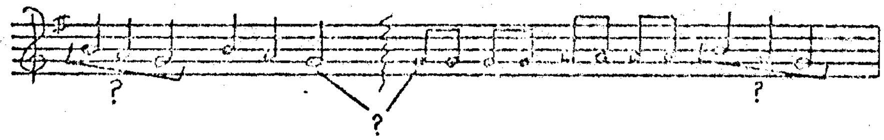
Of particular importance to the research thus far are the individual's ways of representing what I have called "fixed properties" which derive from measuring, logically classifying and naming in relation to a "fixed reference", in contrast to "situational properties" which are dependent on the particular contextual embedding (immediate spatial/temporal proximities) in which an event or a thing is found. While these distinctions clearly derive from the work of Piaget and Vygotsky, I will argue that a child's problems in early learning may be a direct result of incongruences between the child's powerful and useful focus on situational properties and the adult teacher's focus on fixed properties. I have called these two strategies of representation "figural" and "formal".

For example, the teacher may "see" the same shape repeated twice in the figure, below, while the child "sees" no repetition but rather two different things to which he is reluctant to give the same name. Embedded in the figure, the 'same' shape is for the child in different places and has different functions--arms, legs.



Just so, the child (or, indeed the untrained adult) does not hear as 'the same' a pitch or motive which occurs in two different 'places' in a tune and with different function and meaning. He will be reluctant to give the pitch or motive a single name, preferring instead to call them, for example, "first" and "last" or "beginning" and "ending".

HOT CROSS BUNS



I will argue that neither description is right or wrong but rather that each captures different and valid features of the 'same' phenomena. The differences are mediated by the individual's internal modes of processing or representing the phenomena to himself and also by his immediate purposes. ~~Thus,~~ I ~~propose~~ describe, here, an experiment in learning in which the child is encouraged to find multiple meanings and to make multiple descriptions of given phenomena. The materials and approach will stimulate him to "flip focus", to group and regroup, to name and rename elements and aggregates of elements according to varying and shifting modes of representation. It is my thesis that through encouraging the child thus to make multiple descriptions of the same phenomena and even to map one description onto another, he will thereby enrich his own cognitive strategies and also gain powerful tools for finding correspondences, and thus for reconciling incongruences in representation with which he may be struggling in school. The process is much like what Wittgenstein calls playing "language games":

> The concept of 'seeing' makes a tangled impression...Here we are in enormous danger of wanting to make fine distinctions. It is the same when one tries to define the concept of a material object in terms of 'what is really seen'. What we have rather to do is to accept the everyday language-game...Take as an example the aspects of a triangle. This triangle
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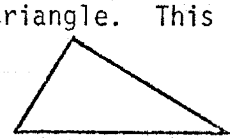
> 
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> can be seen as a triangular hole, as a solid, as a geometrical drawing; as standing on its base, as hanging from its apex; as a mountain, as a wedge, as an arrow or pointer, as an overturned angle, as a half parallelogram and as various other things. "You can think now of this now of this as you look at it, can regard it now as this now as this and then you will see it now this way, now this..." What way? There is no further qualification.

At the same time in such a learning environment, the observer gains insight into the child's intuitive strategies of representation and his means for making transitions from one representation to another. While earlier research in cognitive development has focused on distinguishing the separate levels or stages of development, only more recently has the emphasis shifted to include the learning processes, the transitions and intermediaries which bring a child from one stage to the next. Inhelder et al. put it this way:

> The study of transition mechanisms is, in our opinion, essential if we want to find answers (even if only partial) to the following questions: What are the developmental links or derivations between the different key concepts? What are the dynamic processes that lead to new modes of thought? What is the role and the nature of learning? (Inhelder et al., 1974, p. 243)

It is to these questions that the research has been directed.

Intervention activities are centered in the musical domain. However, it is my hypothesis that while cognitive skills underlying intellegent musical behavior are, in part, domain specific, the character of these interventions may well contribute not only to domain specific growth but to the development of basic cognitive skills in other domains, as well.

For example, the activities provide a fresh, non-threatening medium, a combination of construction with "hands-on", concrete materials together with the invention of descriptions or "notations" both for the processes of construction and the finished product, and also a particularly fertile environment for encouraging multiple descriptions and thus transitional learning. (See Section II for a full description of these activities.) Interestingly, the transfer of learning from the domain of music to other domains appears not only in "key cognitive concepts" but specifically in the representation of cross-modal relations. The child's construction of simple tunes through the use of moveable sounding objects involves him (perhaps surprisingl with descriptions that require the coordination of spatial, temporal, kinesthetic and aural thought schemata. In each attempt to deal with a tune, the child is searchinc for, constructing, and describing a coherent structure which thrusts him into many of the same problems as the search for coherence in other domains. In turn, the child's fundamental strategies of representation are often rather dramatically revealed. (See Jackendoff, R. (1976) for a discussion of "cross field generalization"; Birch-Belmont (1966), Goodnough (1975) for a discussion of "cross-modal" processing.)

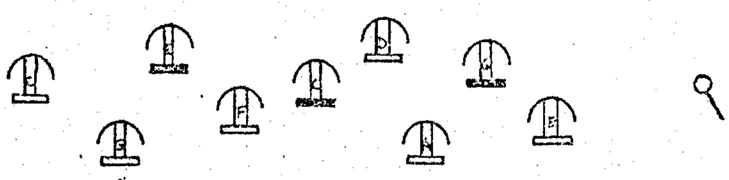
This past year two 8-year old boys (among the 20 children randomly chosen from a Cambridge public school) came to the Lab barely able to read or to do simply arithmetic computations. Almost from the beginning they not only became actively involved in building, describing and inventing notations for pitch/time relations, but through these activities seemed able to confront basic cognitive issues that they were unable or unwilling to confront in school. Further, significant development occurred in their abilities to cope with such basic cognitive skills as conservation, seriation, and logical grouping. Later in the year their teachers also reported surprising leaps in their academic performance and in their general social behavior, as well. While I can quite rigorously describe the nature of the cognitive changes, I need now to find more than speculative answers to the following questions:

1) Why do activities involving the pitch/time relations of music encourage children to participate freely in tasks which clearly challenge their current cognitive skills?
2) What is the nature of these cognitive changes and why and how do these particular materials and modes of learning contribute to them?
3) To what extent will observable changes in cognition in the domain of music be a factor in the child's cognitive changes in other domains?
4) Can the positive experience with two children be repeated with other children?

II. Description: Methods of Intervention--The Experimental Environment

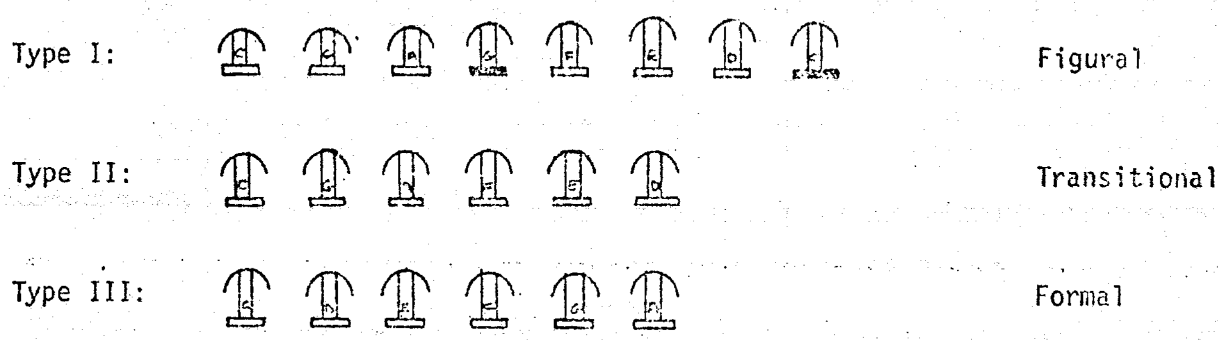
I begin with a model of the intervention tasks in order to define what I mean by cognitive change in the musical domain. The data is derived from observations of both children and adults in one particular experimental situation. This model will serve not only to illustrate kinds of intervention but will also serve as a model for the categories of analysis I will use in describing and evaluating cognitive change. In the next section, I will go on to a few vignettes drawn from the work of one child in order to show the learning process in a more concrete way, i.e. the means by which he restructured and enriched his initial strategies of representation.

The materials in this experiment are a set of tuned bells borrowed from the Montessori teaching materials but used here in a rather different way. The child is given an array of bells, all of which look alike except that a few have brown bases, the rest are white. The bells are separate and moveable; they are sounded by striking with a small mallet:



The white bells include the pitches C-D-E-F-G-A, the brown bells include matching C, G, and E bells (or sometimes a full set of matching brown bells). The bells are not labelled,so the only way to distinguish them is by playing and listening to each one--i.e. by ear. The child knows (from previous matching games) that there is a match between brown and white bells, and that no two white bells play the same pitch. The game is to build a tune with the bells--in this example the tune is "Twinkle, Twinkle Little Star". Once completed, the child is asked to "put on paper some instructions so someone else could play the tune on the bells".

In experiments which included 15 adults (MIT students and faculty) and 12 children I have identified three distinct strategies for constructing and describing the tune. These in turn suggest three distinct internalized strategies of representation. The distinctions are already evident in comparing the completed arrangement of bells for the tune, "TWINK", which results from the three strategies:



(labels on bells are for reader's convenience)

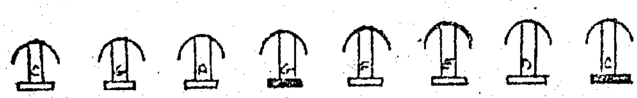
Type I is characteristic of a figural strategy, Type II is transitional--i.e., an intermediary between Types I and III, Type III characterizes formal strategy. Each strategy captures different but valid features of the tune; however, it appears that an earlier strategy is a necessary condition for a later strategy.

A figural strategy (observed both in children and in untrained adults) is highly sensitive to contextual "meaning". A tune event is represented in terms of its "situational properties"--e.g. its position (spatial/temporal proximities) in the sequence of events, or its function (begin, end) in the structure. A figural builder insists on having one bell for each pitch event in the tune* This suggests that pitch property is not abstracted from situational properties or, indeed, from the object, bell. That is, two bells which share a pitch property are heard or

*If an immediately repeated pitch event functions as an extension of the first instance, the same bell is used again. Functionally, the second interation is "more of the same".

described as *different* if they occur in different positions. There is no conservation of pitch over time or contextual embedding.

The figural child's process of *constructing* the tune reflects his internalized strategies. He works *cumulatively* (next-next-next) compiling a "bell path" by searching in the mixed array for each bell in turn for a "match" with each subsequent tune event. With each successful test, a bell is added to the cumulating bell path. The process is uni-directional--the figural builder never turns back to compare a new bell with a past bell. He thus adds a new bell for each pitch event even though a bell with the same pitch property is already present in his emerging bell path:



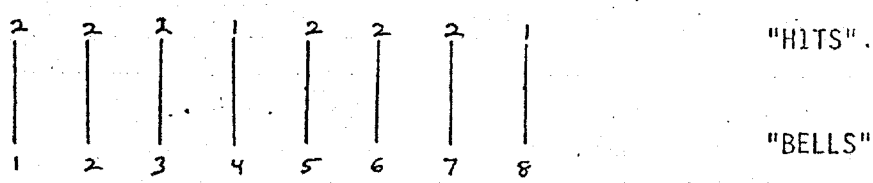
TWINK

For the figural builder, the two G-bells or the two C-bells are not the 'same'. That they share a property is irrelevant both to his process of construction and to his perception; within the context of the tune, they *sound* different. If he is asked, as a separate experiment, to "find the bells that match", he can do so, but he is always surprised to discover that there *are* 'matches'. Further, this discovery (as I shall show) will not initially influence his representation of the tune.

The particular arrangement of bells in the completed bell path permits a performance ("action path") which is also uni-directional. Thus there is a neat congruence between bell path, action path, and the sequence of events in the tune. Bell-space, tune-space and time-space are all unified in a single representational space.

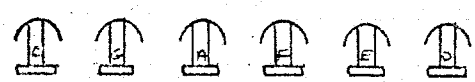
Interestingly, it follows from these strategies that the figural builder can *name* the events in the tune only after-the-fact, i.e. only after they are embedded in the unique context of this tune. He names the bells simply according to their position in the linear sequence on the table. Thus, the names he gives to the bells can apply only to (have meaning for) this <u>particular</u> tune. Names do not refer to a general property of the bells or to some outside fixed "anticipatory schema" (see Piaget, 1960). His instructions for playing the tune must add, as a <u>separate</u> instruction, how many times to "hit" each bell.

INSTRUCTIONS (description)



The bell-path is thus a one-purpose machine; the instructions work only for it, and it plays only one tune.

Finally, the description is "iconic" rather than "symbolic". That is, the child makes a picture-copy of the bells on the table and simply tells you "how to go on them"--namely, "straight ahead". In fact, the lower numbers are not really necessary for the instructions and are often added only at the observer's urging. However, the figural child's instructions will work exactly because action path, bell path, and tune are all congruent. Indeed, the bell path is, itself, a description of the tune.

Type II:  Transitional

Type II builders differ from figural builders in several important ways:

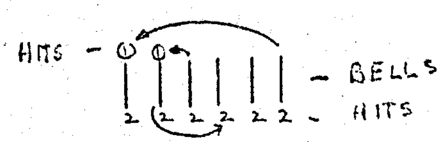
1) While bells are found and added cumulatively according to the initial occurance of a pitch in the tune (like a cast of characters in order of appearance), <u>there is only one bell for each pitch-type</u>. Thus, a single bell is used for each occurence of that pitch in the tune. Thus there is conservation of pitch over position/function and route traveled.

2) The "action path" is bent--i.e. the child must turn back and skip bells

in order to play the tune on his bell path. (C-G-A, back to G, skip to F, E-D, back to C.)

3) As a result of 1) and 2), the bell path, action path and tune sequence are no longer congruent; action path has come apart from bell path, bell path from tune sequence. Thus, the bell path is no longer, itself, a description of the tune. Rather, the tune must be represented through a mental coordination of action path and bell path.

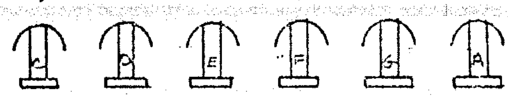
Instructions made by Type II children are still iconic. They include a combination of pictures of the bells and a kind of action notation. The result is a sort of map with landmarks over which directions are traced to show you the route:



Type II is not only a clear transformation of Type I strategy, occurs chronologically between Types I and III, but most important, appears to be a necessary intermediate condition for formal strategy. Consider that as long as the child's focus is on situational properties, then no two events can be represented as "the same" simply because they occur at different times. More specifically, as long as pitch property is not represented as a separate attribute of an event or of a bell (when embedded in the bell path) but is fused with the immediate, local effect of the event and with the immediate "presence" of the bell in the path, there can be no identity of elements. Type II children succeed in making this crucial "defusion." It is not surprising that this defusion coincides with the coming apart of bell path and action path. The Type II child also succeeds in coordinating action path and bell path. These separations and coordinations are necessary for formal representation because without these restructurings the child cannot construct a "fixed reference" based on general properties of pitch (and of the bells) and in relation to which he can describe and name the particular events in this tune or any tune before-the-fact. These steps are also crucial to the development of symbolic descriptions and to the encoding and decoding of standard music notation, as well.

The formal builder begins by building just such a fixed reference--a kind of all-purpose instrument. Searching in the array of bells with quite different purpose from Type I or Type II builders, he constructs a seriation of the bells according to the "anticipatory schema" which the children describe as "you go lower and then higher, higher, higher"--i.e. a scale. This, in itself, is a significant cognitive leap (see, of course, Piaget on seriation of sticks) since it involves keeping in mind a set of relations which constitute a plan, a scheme, held in imagination, which is used to generate a particular structure. (The issues surrounding seriation of pitch are interesting in themselves, but I cannot deal with them, here.)

The scale completed, the child's construction activities are finished:



This scale arrangement now reamins fixed in space. It serves as a fixed reference for finding and naming the sequence of events in the tune. The tune is made, then, by searching ON the fixed scale path for the particular sequence of pitch events in a given tune. This involves moving about on the scale--forward, backward, skipping--in a process of mapping an action path onto the scale. The sequence of tune events is now quite separate from the bell arrangement. Since there is no spatial-temporal congruence between scale path, action path and sequence of events, the congruence must be constructed through a mental coordination (mapping) of one set of relations (tune) onto another (scale). This requires as a first step, precisely the strategies which distinguish Types I and II--namely defusing (coming apart) of situational properties such that pitch is not influenced by spatial-temporal embeddings (conservation of pitch) together with the defusion of action path from bell path and sequence of tune events. In short, Type II is a transitional form of "decentring".

The child begins to "reflect on" his actions and on the particular properties of the tune, pulling himself away from the compelling force of the contextual meanings generated by the well-formed shape of the tune. But the formal builder builds a single, consistent coherent structure of pitch relations which he can then coordinate with the particular coherence of a given tune. In this way too, the focus shifts to measuring pitch distance along the scale grid--a kind of "objective measure" which is so characteristic of formal thinking.

Instructions show a leap into symbolic description. There are no pictures. Instead only the numbers name events in the tune according to the fixed reference. At the same time the numbers measure the distance relation along the scale grid from one event to the next and also among events as a whole. In addition, the notation coordinates, in one symbol, number of hits and the place of the bell on the grid in contrast to Type I or II descriptions where hits and bell-names were kept separate. In this formal representation of the tune, the tune is "seen as" a particular realization of the scale. As such it necessitates description through the use of symbols which can reflect this coordination:

1 1 5 5 6 6 5 4 4 3 3 2 2 1

The child has invented symbols which fix events in a kind of coordinate space. The horizontal progression (notation path) shows "tune-space", the numbers indicate where to find those events (action path) in the "bell-space".

The issues raised by this model go well beyond those of simply tune building. The contrasts between figural representation and formal representation are similar to those Piaget has described in the development of intelligence, generally. Piaget contrasts "intuitive" with "operational" thinking. Working in other domains such as temporal relations, seriation of sticks, rotation of objects in space, formation of classes and class inclusion, Piaget rigorously describes the internal consistency of intuitive thought:

> Intuition being a direct relationship between a schema of internalized action and the perception of objects, results in configurations 'centered' on this relationship. Since it is unable to go beyond these imaginal configurations, the relations that it constructs are thus incapable of being combined. The subject does not arrive at reversibility because an action translated into a simple imagined experiment is still uni-directional, and because an assimilation centered on a perceptual configuration is necessarily uni-directional also. Hence the absence of transitivity, since each centering distorts or destroys the others, and of associativity, since the relations vary with the route followed by thought in fashioning them...thus, there is neither a guarantee of the identity of elements nor a conservation of the whole. (Piaget (1950, p. 138))

Applying this to figural modes of representing tunes, we see that the figural child's focus is also centered on the local, uni-directional relations of the tune configuration--e.g. immediate spatial, temporal proximities of the uni-directional bell path still fused with the uni-directional action path. He thus 'distorts or destroys' in his thought the particular properties and relations which might have occured in favor of constructing new relations as a result of the contexts generated by the route he is following. Clearly, then, to describe an 'identity of elements' is impossible for him--a present pitch cannot be identical with a past (or passed) pitch. Nor can he 'combine' a 'bent' action path with a uni-directional bell path and sequence of tune events. This is precisely what I mean by sensitivity to context--the meaning of an event is always immediately responsive to the context in which it is embedded.

Operational thinking, in contrast, makes use of an "anticipatory schema":

> ...thought is no longer tied to particular states of the object but is obliged to (adjust to) successive changes with all their possible detours and reversals; and it (thought) no longer issues from a particular viewpoint of the subject, but coordinates all the different viewpoints to a system of objective reciprocities. (Piaget (1950, p. 139))

Translating this to tune builders, we can say that the formal builder is no longer tied to the "particular state" of the object or event (unique contextual situation) but instead removes herself from these qualitative impressions, adjusting the pitch-event so as to map it each time onto the invariant (objective) system of ordered pitches--the scale. Naming thus becomes invariant to position or function in the tune and loses its sensitivity to context.

Clearly, formal strategy looks more like what the child may expect to find in school. Indeed, if he is to learn to read music, to play an instrument, or to acquire math skills and learn to read, he must be able to abstract and name properties regardless of their situational influences, classify them appropriately, measure them, group them and relate these aggregates to form higher level relations. Further, he must be able to reflect on his own actions, "turn back" on them to compare objects that are distanced in time or space. These formal modes of thinking are too frequently simply tacitly assumed in classroom teaching.

And yet, I would argue, figural representation is not merely a phase to be overcome--it is, for example, crucial to the understanding and to the affective response to music. Function,position, immediate proximities are all essential influences on musical "meaning". Unlike a formal class (the class of all bells, the class of all G-bells), a tune exists in time, indeed structures time; one needs to respond to the unique present moment. (Roger Sessions once said, "You know, I find it more and more difficult to use plurals".) And yet to read music, to play an instrument, one must recognize that a pitch has a single place on the musical staff and on an instrument, a single name regardless of context and effect. The truly understanding listener or performer must be responsive to both situational and fixed properties. One of the pleasures of musical experience is the discovery of the transformations which context can perform on "the same" pitch or group of pitches.

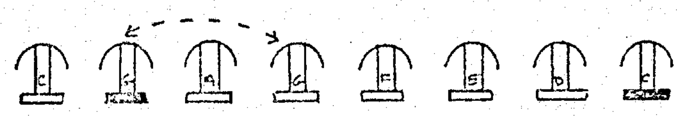
The trick, then, is to learn to shift freely back and forth among strategies--flipping focus leads to the discovery of new features as salient, to grouping and regrouping and to the construction of new and different relations. Indeed, this process of making multiple descriptions is much like what Minsky calls "frame transition" (Minsky, 1975) which,while not well understood, seems fundamental to problem solving and to creative insight. Further, such ability to coordinate different representations leads to the discovery of correspondences and to the reconciliation of incongruences in representation which inhibit communication and learning.

III. Vignettes--1 Jeffrey's Story

An individual's strategies of representation are a vital mechanism for making sense of the world. If it is shaken up, taken away, the child (or the adult) is left in confusion, afraid and angry. Jeffery, for example, is black, eight years old, and came into the Lab barely able to read and with only a minimal sense of number. He talked little (and reportedly "not at all" when he entered school in first grade). He was, however, a very effective figural tune builder.

As an illustration of his tenacity in maintaining his own ways of understanding, his own internal representations, consider the following situation: Jeff had been working in the Lab for about two months, two hours per week. During that period he had returned to "Twink" frequently, but made other tunes as well. I asked Jeff to "arrange the bells in order from low to high". This way of describing the relations was meaningless to Jeff since it involved dealing with relations among the pitch properties themselves, rather than with the relations determined by the succession of events in a tune. This was clear since, when I sang a scale and said, "Can you build this tune?", Jeff had no problem at all. Once built, I showed Jeff how to play the beginning of "Twink" ON the arrangement--i.e. without moving the bells, a formal strategy. He watched but looked noticeably uneasy. Instead of imitating what I had done, he picked up the C and G bells, hugged them to his chest, and put them down on the table next to one another. He quickly took apart the rest of the scale arrangement, searched for and found the two necessary brown bells and rebuilt his original bell path, all in one uninterrupted process. His tune was back together again; it was evidentally painfully confusing to hear it looking so different. And still Jeff's response was direct and immediate. He needed to and knew how to fix up his confusion; he had built up his own model of the tune and could make use of the same strategies to build it up again. He could have played "my tune" in a rote fashion but he felt free not to. I was continuously impressed with Jeff's quiet insistence on being true to himself, even though it may have looked to others as an "unwillingness or inability to learn".

In another session Jeff had once more built "Twink" in his usual figural way when I asked him, "Can you find the bells that match?" This was no problem for him as a separate experiment. But, still, Jeff was always surprised to discover that there were matches in his tune. Having found the two G-bells, I suggested that since they were the same, he could play the tune if we took one of them away. Jeff shook his head and thought for a moment. Then remarkably, he switched the two G-bells:

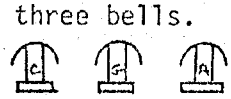


One bell could substitute for the other, but they were both necessary as place markers along the bell and action paths.

Inhelder et al. describe this kind of reluctance or inability to integrate experiences which involve two separate strategies as follows:

> The disequilibria are experienced by a child as conflicts or contradictions. His efforts to resolve such conflicts lead to interactions between schemes, and it is these interactions that often result in the compromise solutions or partial compensations invented by children just before they become able to give fully compensatory operatory solutions. (Inhelder et al., 1974, p. 259)

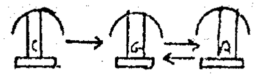
A month or so later, Jeff succeeded in building "Twink" in Type II fashion, but his problems along the way are revealing of these transitional processes. Jeff quickly found the first three bells.



Not finding the next bell among those remaining (he had only the white bells to work with), he searched among the bells already in his bell path. Finding it there, he smiled and said, "I had it already". This was an important shift in strategy and an important discovery, but its implications did not take effect right away.

Once more starting from the beginning of his bell path, he tested his discovery.

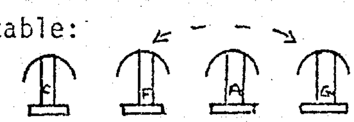
Playing the three bells in order, he visably hesitated and then, almost reluctantly, turned back to strike the second bell again:



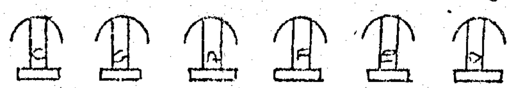
This was a big wrench in his strategies as is clear from what happened next. Jeff found the next bell (F) among the remaining bells in the mixed array and added it to his cumulating path:

Now, starting once more from the beginning to check his tune, the pull of a uni-directional action path congruent with the bell path was too seductive. He played straight on through the fourth bell without turning back:

As a result, Jeff heard a different tune! What could he do to fix that? He thought for a moment and then surprisingly, switched the second and fourth bells. Why? Perhaps he was reminded of the previous situation. In his Type I construction, the second and fourth bells were, indeed, the same, switching them kept his tune in tact; did Jeff think this could <u>fix up</u> the situation here? Or did he think that changing the position of the bells would change their sound--"turning back" the bells might be like "turning back" in his action path. But playing this new arrangement, now, the tune was hardly recognizable:



Looking hopeless, he sought comfort in his old ways: He said, "I need another bell." Jeff was clearly in transition, struggling with the incongruences between two representations--incongruences between bells as place markers and the pitch properties of bells invariant to place; incongruences between action path and bell path. I helped him to readjust the bells and pointed out that a turn back necessitated skipping a bell in order to go on. With this "bending" of the action path in mind, Jeff finished building the tune and he had no trouble turning back at the end:



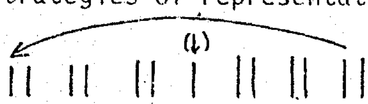
From this example the processes of transition become quite clear. Jeff is struggling with a new representation of the tune which includes a focus on new features and new relations. For example:

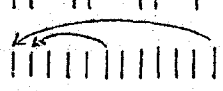
1) The pitch-property of a bell can be represented as separate from its position in space and in the tune. He is beginning to conserve but he slips in and out of it.

2) The bell path can be distinguished from the action path and the tune sequence. His description of the tune *as* the bell path is changing so as to include the freedom of moving *on* it in order to coordinate 'same pitch' with 'new event'. But the seductive pull of a single, unified representation is still there.

3) The fusion characteristic of situational properties, is de-fusing into fixed properties--e.g., pitch, position in space, position/function in the tune. For example, "first" and "last" in the tune can be "the same" in pitch and position. Jeff is developing new strategies of representation which will influence both apprehension and naming.

Jeff's instructions evolved in one, half-hour session through a series of extraordinary modifications that seemed to mirror the transitions taking place in his strategies of representation.

1) 

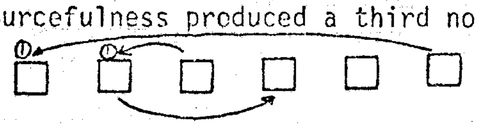
2) 

1) is clearly transitional. Surprisingly, Jeff's lines now show *actions* (hits) rather than bells--he "plays" the tune on the paper. That two hits apply to the same bell is shown by grouping the lines together spatially. However, just as the pull

of the bell path seduced the action path, so it seduces the notation path, once more reflecting his "slippage". The notation path goes continuously onward <u>through the fourth bell</u> (one hit, single line) instead of turning back--exactly what Jeff did when he first added the fourth bell in constructing his bell path. The turn back at the end is captured, though, by a new arrow notation--an action notation.

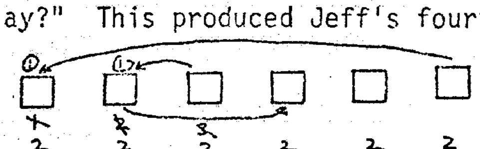
A test of his notation (playing the tune again correctly) resulted in 2) showing the first turn back but pointing to the wrong place--the principle, but not its particulars. However, repetitions of bells are no longer shown--there is simply a chain of hits. I asked, "How will people know that some of the bells are played twice?"

Jeff's resourcefulness produced a third notation:



Now 'same bell' is illustrated by joining together the two hits which are struck on a single bell. And the first turn back arrow now points to the right place.

Finally, I said, "Could you put in some numbers so people will know exactly which bell to play?" This produced Jeff's fourth notation:



Jeff begins numbering the boxes (which he created by joined lines) in a serial fashion--1 2 3, but when he got to 3 he rejected the numbers as names for the ordering of the bells (the crucial "bend", again) and slipped into numbers as "counts" for hits. He said, as he numbered, "You play this one twice, and this one twice..." The slippage was pervasive. Joining the lines together made boxes which in turn transformed their referents--the hits turned into bells. Similarly, the referents for numbers switched from bells (count-on) to hits (counting-up).

Slippage in this fashion can be seen as reflecting the limits of Jeff's capacity for symbolization; he lacks a stable, systematic structure in relation to which he can consistently <u>name</u>. Indeed, the whole process reveals not only the characteristics which distinguish figural and formal representation but also the nature of the learning involved in making the transition.

Piaget says of this transition:

> In this there is something comparable to the abrubt complex restructurings described in the Gestalt theory, except that, when it occurs, there arises the very opposite of crystallization embracing all relations in a single static network; operations, on the contrary, are found formed by a kind of thawing out of intuitive structures, by the sudden mobility which animates and coordinates the configurations that were hitherto more or less rigid despite their progressive articulation. (Piaget, 1950, p. 142)

Towards the end of the year, Jeff finally did make the transition. Building a scale (seriating the bells) and playing the tune <u>on</u> the fixed arrangement led to a rather remarkable notation:

[1] [5] [6] 5 [4] [3] [2] 1

The boxes, derived from his previous notation, show which bells to hit twice. But now these boxes take on a nearly symbolic function: □ = bell. And the numbers add another dimension to the symbol, namely, [□ + number] points to the position of the bell in the fixed reference. These are truly symbolic names which remain consistent because they derive from a single, stable structure. Indeed, in explaining the notation to another child, Jeff said, "Look at the numbers; this is the 1-bell, this is the 5-bell..." In fact, Jeff has invented a symbol system which coordinates events in two spaces: The horizontal progression of boxes and numbers refer to the "tune-space" (progression of tune events) including how many hits, the numbers also refer to the "scale space" and indicate a particular place in it. The notation provides the means for mapping one "space" onto the other. Jeff has come very close to inventing standard music notation.

Perhaps the most significant aspect of this whole, long process is that Jeff has learned to risk shaking up his strategies of representation--i.e. he dares to restructure and to transform his way of thinking a tune. One of the biggest risks involved was letting go of the present moment, the immediate, concrete, local "reality" to <u>build</u> relations and structures which are only possible in imagination. This is because he can coordinate realities which in immediate wxperience remain quite separate. And conversely, Jeff has dared to take apart in imagination properties which are always fused in immediate experience--like pitch and bell object. Each new reconstruction creates a new way of thinking the tune--what Piaget sometimes calls a new "thought schema". While the strategies necessary for such reconstruction seem more characteristic of formal thinking, their acquisition results not in a greater rigidity, but rather in a greater freedom of thought.

Indeed, the mobility of thought--the ability to shift or restructure ... thought schemata--leads to a new notion of context-dependent meanings. If we think of thought schemata as contexts which mediate meaning, a shift in thought schemata will result in a shift in meaning. Mapping one thought schema onto another will then allow for a multi-dimensional description with interactions between and among them. For example, Jeff's initially figural thought schema was reflected in sequential names for tune events--1 2 3 4 5 6 7 8--one bell for each event, none the same in name or apprehension. His next thought schema included identity of pitch property reflected in naming recurrence of the same pitch with the same name--1 2 3 2 4 5 6 1--one bell for each pitch-type, apprehension of same pitch in spite of different positions in tune and action path. Shifting from one thought schema to the other, the tune-sequential name, "4", becomes the pitch property, "2". While in both descriptions names derive initially from the order of occurrence in the tune, in the latter description some events gain new meanings--i.e., identity of pitch property.

1 2 3 4 5 6 7 8
1 2 3 2 4 5 6 1

With this potential for constructing new thought schema and with it new meanings, Jeff could go on to construct still another one--the serial ordering of pitches according to the property, "low to high"--a scale. This thought schema generates a "fixed reference" from which names and meanings derive--

1 2 3 2 4 5 6 1
1 5 6 5 4 3 2 1 .

The initially sequential name, "2". now becomes the fixed reference name, "5". And, interestingly, this includes a shift in meaning for near and far--two events close to one another in the tune (1 2) are far apart on the fixed reference (1 5). However, in the latter schema, names and meanings are no longer tu specific, no longer responsive to the unique contextual situation of an event in the tune. Mediated by the schema, bells sound the same comparing one to the other and both to the fixed reference. But the process of shifting from one thought schema to another provides a way of capturing again the power of context dependent meanings: Names are liberated from things--naming is a game, a language game the rules of which you can invent. In this way a thought schema becomes a context for inventing rule-like constraints which can transform meanings and apprehension; names in turn, will capture differing features and relations as mediated by the thought schema. Within one game a single pitch may be named "2" while in another, "5". In this way, shifts in thought schemata lead to the apprehension of two events as either the same or as different, depending on the schema in which one chooses to embed them.

In fact, Jeff has set the stage for integrating situational and formal properties. The crucial step is the notion of mobility of thought schemata or of language games ruled by thought schemata which mediate meanings. For example, it is not a big step, when playing this game, to understand that "same pitches" may have different functions as they occur in the context of different musical environments. In this game names capture the changing apprehension of pitches in response to the musical context in which they are embedded. A G embedded in one set of pitch relations will be apprehended as unstable; a G embedded in another set of pitch relations will be apprehended as stable. These are differences in the function of the pitches. We can invent a thought schema to capture these differences--a schema which names pitches according to their relations with one another (interval relations) and according to their harmonic functions (tonic-dominant). In this language game the pitch, G, can be called 5 (or dominant) in the key of C reflecting its apprehension as generating a particular kind of instability; or it can be called 1 (tonic) in the key of G reflecting its apprehension as stable. Now names like 1 and 5 which previously stood merely for positions on the scale grid, become a short hand for higher level relations which capture a whole network of interrelated functions. The names reflect functions and relations which remain stable in the thought schema, but the names change their particular referents (pitches) in response to the particular musical situation in which they are embedded and apprehended. This illustrates the process of mapping one thought schema onto another (pitch identity (G)⟺ tonic-dominant). The process in turn leads to the possibility for apprehending transformations--a pitch (or motive) transforms when, while remaining invariant as "measured", it changes meaning in response to its situational embedding.

In this way an initially figural strategy can be enriched by more formal strategies each giving power and definition to the other. Indeed, we have come full circle--Jeff's first strategy of representation in which each pitch event was new and different can be understood as neither right nor wrong, but as reflecting one dimension of a multi-dimensional description of the tune. Looking "through" these various dimensions as through layered, transparent filters, we see that the meaning of "the same" pitch can transform in response to its situation--G in the middle of a phrase with a shorter duration is apprehended differently from G at the end of a phrase with a longer duration. The first occurrence of G is both the same and different from its second occurrence, changing its name and its apprehension as we move through the layers of thought schemata to integrate them into one single, richer experience.

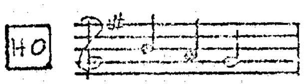
IV. Vignettes 2--Computer Music Games

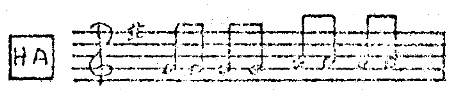
Jeffrey's growth was probably also influenced by the use of computer-music games. Only two examples will be given here. The music system permits the child to work interactively with the computer by typing commands at a terminal. His commands are instantly realized in sound. One game involves playing simple rhythms on a drum which he can describe in a variety of ways. For example, the rhythm ♫ ♩♩♩ is often spontaneously described in a spatial analogue: ||| | | . This can be translated into the relational names, short (S) and long (L): S S L L L In turn, these can be used as commands to the computer which will immediately play the rhythm back as "drum" sounds much like the child's own. But most important, the child can "teach" his drum tune to the computer (write a computer procedure) so that this rhythm can be used as a module in a bigger drum piece or as an accompaniment to a tune. This engages the child in inventing meanings (as he defines his figure) inventing names which refer to these meanings, and in aggregating or "packaging" the separate discrete events of his rhythm so that he can build higher level relations among these aggregates. Typically, the child will begin by simply repeating the names of his invented procedure. Let's say he calls the above rhythm "FUNNY". If he types FUNNY FUNNY FUNNY, he will hear three iterations of his original rhythm (♫ ♩♩♩ ♫ ♩♩♩ ♫ ♩♩♩). This means that he is dealing with the five initially separate bits (S S L L L) as a single chunk, a single entity.

Through this step he can go on to use a higher level language, namely, REPEAT FUNNY 3. This produces the same three iterations of his original rhythm, but the description is different; it involves understanding the relation, "REPEAT" and the use of the number, 3, as, itself, a packaging of three smaller units.

Through such activities, Jeffrey, for example, learned the principle of aggregating, of hierarchic relations, and relations of parts to wholes. He moved freely back and forth between the levels of the hierarchy sometimes taking an aggregate apart, sometimes chunking his individual drum hits into aggregates.

Another game used frequently by children is called "tuneblocks". Pre-programmed procedures provide the player with short tune segments (tuneblocks) which are actually reasonable structural chunks of a familiar tune. For example, if he types, HO, he will hear the first motive in HOT CROSS BUNS; if he types HA, he will hear another motive:





The game is to arrange these blocks in order so that, like building blocks, they will make up (play) the whole structure. The whole tune, HOT, is also available for him to hear with the command, HOT.

Surprising aspects of the child's representation of the tune emerge in observations of his playing. Typically, his strategy is not dissimilar from figural tune building with bells but now he is working with larger structural elements (aggregates of notes rather than discrete pitches) and only listening. With no concrete materials to manipulate, he must construct descriptions mentally. Typically, he will search in the collection for "the first part", then continue his search until he finds "the second part" thus, again, building a path of elements which are processed "in time" one after the other. But, as a result, the problems of repetition and identity of elements once more emerges, this time in more dramatic form. For example, in playing with HO and HA, the child will make a path (type in order) HO HA having identified these as "the first and second parts". He is surprised to discover that it doesn't sound right. Only with considerable thought does he discover that he "needs two HO's": HO HO HA. The situation is puzzling: evidentally the problem is in his representation of "an element". Does the element named, "first part" incl[ude] the repetitions in the child's representation? Is a single instance sufficient because there is only one kind of thing? Also involved is using the same name for elements which occur one after the other and thus have different effects.

The issue becomes more acute as the child tries to find "the last part". Described in this way, the last chunk of the tune seems to require something different--at least a new name which reflects a different function. Jeffrey, for example, could sing the completion of the tune (the HO block) after listening to the computer music box play HO HO HA. But evidentally his representation of this "ending" made it difficult to describe it with the same name as the "beginning". His own internal representation focused on function and position in the sequence; this was incongruent with formal focus on pitch-rhythm properties from which view "begin" and "end" are identical. Jeff's representation and his apprehension changed when he discovered that HO would do for both.

Joey, the other child with whom I worked, invented the notion of "making a dictionary" to help with this issue of identity of properties. Each item in the dictionary is a tuneblock and the "definitions" include all the properties of the block the child can describe. For example, HO: "three things in it"; "slower"; "goes down". These descriptions served to shift the child's focus to fixed properties which in turn allowed him to find identities in spite of different contextual embeddings.

Many of the same cognitive issues arise in these games--naming, relation of name to thing, multiple descriptions, identity relations. And in addition there is a spin-off which involves reading and writing, directly. That is, not only does the child deal directly with words while typing at the terminal, he also discovers, for example, that words are parsed as chunks in sentences by the formality of inserting a space between them. This is as true for the computer as for the human reader. If the child forgets the space, and types, for example, HOHA, the computer sends him a message, "You haven't told me how to HOHA". He has made a new word "HOHA" which the computer doesn't "know". The child rather quickly discovers that he and the computer are sharing a "culture" the rules of which are much like his own but the computer has the consideration to make the rules explicit and to stick to them. He learns to read and appreciate the computer's messages and to respond to them as a helpful aid. He also learns that there are no "right" or "wrong" answers in this non-threatening, contained world. Whatever he tries will lead to some action. An unexpected result is often more interesting than what he planned; in any case, it is almost sure to lead to new investigation and to new knowledge which he can use later.

In all these ways the child seems gradually to become an independent, self-sufficient learner even taking an active part in shaping his environment. Finding and making meanings, shifting focus to make new meanings, participating in active communication his representations of knowledge become richer and more flexible. Indeed, as the children move freely back and forth between performance on real instruments (bells, drums, singing) and computer games, they seem gradually to enrich their intuitions. They are soon singing in tune, inventing more interesting melodies and drum rhythms as well as playing and improvising together and learning to appreciate the compositions of other composers. One of the most gratifying spin-offs of these apparently constrained activities is the degree to which they seem to enhance spontaneous growth in musical taste and the immediate apprehension of "quality" in works by serious composers. But that is another story which must be told next.