COLLECTIVE SCIENTIFIC DISCOVERY BY YOUNG CHILDREN

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This paper proposes a conceptual model of the processes by which children acquire knowledge through their interaction with peers in dialy life situations. It explains this model through a demonstration case involving the acquisition of "folklore" knowledge regarding the making of ice. The proposed model is different from the Vygotskian vertical interaction model in that it assumes that the member who is most capable in a group can change from moment to moment during the processes of knowledge acquisition. Furthermore, the model differs from the Piagetian horizontal interaction model in that it takes into account the adult's roles in setting up the situation and in temporarily acting as a more capable peer. According to the model, the processes of knowledge acquisition through peer interaction consist of cycles of four stages : 1) the initiation of information seeking, 2) the production of a number of hypotheses, often implicit, 3)the informal experimentation, and 4) the collection of data and induction.

Key words : Knowledge acquisition, Peer interaction, Piaget, Vygotsky.

This paper present a conceptual model of the processes through which children acquire knowledge in intreaction with peers in daily life situations.

It is well known that social interaction plays an important role in the acquisition of knowledge of the physical world. There are two distinguishable types of social interaction. One is vertical, represented by adult-child interaction, and the other is horizontal, as in peer interaction. Vygotsky (1978) emphasized the importance of vertical interaction. He pointed out that a child could do more than what he/she could do alone "under adult guidance or in collaboration with more capable peers" (p.87). His model originally concerned the levels of performance and/or problem solving strategies on intelligence test items. However, if we regard the acquisition of knowledge as a sort of "open problem solving", this model can directly be applied with the depth of acquired knowledge replacing the level of performance. This applied model of knowledge acquisition through vertical interaction does not necessarily emphasize the role of direct instruction by a teacher, as it has often been interpreted in connection with Vygotsky's discussion on "scientific concepts" (as against "spontaneous concepts"). Such an interpretation is too narrow for his general concept of "from interpersonal to intrapersonal". Rather, his assertion should be interpreted as suggesting that the development proceeds through the following processes : At the beginning, an individual can take care of a part of the problem to be solved, and then gradually comes to take on responsibility

for the whole by himself/herself. In these processes it is the more capable member of the society that takes charge of those parts which the beginner cannot handle. The Vygotskian model seems to have assumed that one member (i. e., the developed person) continues to be more capable than the other (the developing individual) at every moment in all the phases of problem solving. Considering that even adults can sometimes be helped by, and learn from, children in interaction, it is not reasonable to assume that which member is more capable is fixed throughout problem solving processes. We need a more dynamic process model which can take into account that which member is more capable can change from moment to moment in the processes of problem solving (or knowledge acquisition). We will describe this point below in more detail.

In contrast to Vygotsky, Piaget claimed that the horizontal interaction was important in the acquisition of knowledge in educational settings (Piaget, 1969 ; Duckworth, 1964). He did not specify the processes of knowledge acquisition through this interaction nor the nature of knowledge acquired thereby. Piaget himself was primarily interested in demonstrating that the structures of intellectual operations were identical to the structures underlying social interactions (Piaget, 1965). However, recent Piaget inspired studies have demonstrated that knowledge can be acquired through peer interaction (e. g., Murray, 1972 ; Miller & Brownell, 1975 ; Doise et al., 1974 ; Perret-Clermont, 1980). The tasks used in these studies were primarily the conservations of weight, length, quantities of liquid, or number (Murray, 1972 ; Miller & Brownell, 1975 ; Perret-Clermont, 1980), and copying geometric figures (Perret-Clermont, 1980) ; the knowledge to be acquired was a sort of procedural decision rule. Children in groups of two (or three), consisting of a conserver or superior and a nonconserver or inferior, were required to deal with a given task in collaboration, and their performances on the posttest were compared with the performances of children who had been required to carry out the same task alone. These studies have found that peer interaction facilitated congnitive structuring not only for inferior children but also for superior ones. It should be noted that this was achieved without an adult's direct instruction or external reinforcement. According to the authors of these studies, this is because the awareness of the presence, and thus an attempt of integration, of different points of view were more likely to occur in peer interaction than individual problem solving.

This experimental Piagetian model for knowledge acquisition has at least two difficulties. First, it unreasonably neglects the role of feedback from the external world, i. e., through "epistemic observation" or "active experimentation", in the acquisition of knowledge. In the Piagetian studies described above, children were not usually permitted to do any experiments in order to examine their conflicting ideas. All that they were allowed was to exchange their opinions.* It is not realistic to think that knowledge is usually acquired through equilibration, without external feedback. The second

*In a study on the conservation of quantities of liquid by Perret-Clermont (1980), children were permitted to use a glass as a sort of measure, if they would like to. However, Perret-Clermont did not comment on the importance of this aspect.

difficulty of the Piagetian model is to ignore the role of the adults who set up the situations for children's problem solving/knowledge acquisition. Even in the experimental peer interaction situations described above, an adult (experimenter) played an important role in the sense that she directed the children to begin the work in collaboration. In daily life situations apparently spontaneous peer interaction is in fact likely to proceed under the indirect influence of adults. Therefore, an adequate model of knowledge acquisition through peer interaction should take into account the adult's role as well. We would like to propose a model eliminating these difficulties.

The Model

We assume that younger children can acquire knowledge without adult's direct teaching, by their collective enterprise in a group whose members share an interest in a certain topic. Unlike adults or older children, they cannot readily acquire knowledge when they individually attempt to do so. In other words, we regard a group whose members share an interest as a system for knowledge acquisition. Each child does not have cognitive ability enough to acquire the target knowledge by himself/herself, but he/she can contribute to the system by saying things about the topic, by informal experimentation from his/her point of view, etc. Consequently, knowledge acquisition can adaptively be achieved by the whole system. In this system who contributes more tends to change from moment to moment in the inquiry processes. That is, the order of "capability" is not fixed as it is in Vygotsky's "vertical" interaction.

In our system an adult may function in two ways. First, the adult sets up situations where children are able to be engaged in their inquiry in a group. He/She provides them with equipment and/or materials to manipulate, explore, etc. He/She also sees to it that children interact with one another smoothly without much quarreling. Secondly, he/she may sometimes take a role of a "more capable peer" in an attempt for knowledge acquisition. When peer interaction comes to a deadlock in the inquiry process, i. e., when none of the children can achieve a breakthrough any more, the adult can take over the role which a more capable peer would play. For example, he/she can give an example which will stimulate the children's thinking, or can help them clarify ideas they have put forward. It should be emphasized that taking over the child's role is all that he/she does ; he/she is not expected to transmit verbally the knowledge to be acquired nor direct what the group is to do next. He/She indirectly supports the children's peer interaction, respecting their motivation for knowing, so that the interaction will effectively result in acquiring the knowledge. We will describe our model, which might be called an eco-social Piagetian model (or a dynamic Vygotskian model if you like), in more detail below, by using a case of the acquisition of "folklore" knowledge of making ice as an example.

Most of the knowledge acquired through children's peer interaction in daily life situations can be called folklore knowledge. This knowledge has the following features : a) it concerns an event in the natural world ; b) it is based on empirical evidence ; c) although it has some conceptual component, it is primarily procedural, and relatively isolated from other events as most people perceive them ; it can often be stated as [If we do X, then (it is likely to have) Y] or [In order to get Y, do X]. Let us give you an example. Suppose that day care children are allowed to sow flower seeds at any place

they like, and that they compare their results with one another. In this situation they are likely to get some knowledge on plant growth, such as "If we step on a place where the seeds are sowed, the buds will not come out," "If we do not give food (fertilizer), we cannot get big and lively flowers." "If we give too much water, the buds are not out." These are examples in folklore knowledge. Although in this case children do not understand mechanisms underlying plant growth, they acquire some procedural knowledge concerning what contributes to the growth of buds and blooms. In addition, they often acquire some conceptual knowledge as well through analogies with human beings. The following utterance by a child is a good example---"Flowers are like men. If flowers eat nothing, they will fall down of hunger. If they eat too much, they will become ill." (Motoyoshi, 1979, p.136).

Before going into details of our model, we would like to illustrate it with a brief description of how a number of children went about making ice (See the appendix for details), as observed by Motoyoshi, an experienced teacher of a day care center in Tokyo, and reported in her book (1979). Though probably incomplete as an observational document, in that the teacher (recorder) was likely to omit some events that did not attract her attention, this case is interesting in itself, because it shows that "folklore" scientific knowedge can be discovered through collective enterprise by day care children who have been encouraged in peer interaction, and we think it is quite useful to illustrate our model.

Making Ice

When several 5–6–year-old children were playing by stepping on a frozen swimming pool, one of them uttered a question. "Why are there days when the water of a swimming pool freezes and when it doesn't ?" This question interested a group of children there. They were motivated to discuss this topic, and through this discussion they strengthened their motivation to know about this phenomenon. As a result, they decided to try to make ice by themselves. The children chose the vessels they liked and left them filled with water in the places they liked before they went home. Next morning they compared the results with one another in terms of whether or not the water in their vessels had frozen. Then they found that the water in the same kind of vessels did not always turn into ice with the same thickness, and that water in the vessels which had been put in the same place did not always freeze in the same way ; some froze and others did not. These findings motivated them to do "experiment" for making ice repeatedly for several days. On the ninth day, they could specify relatively well the conditions under which water freezes, i. e., they had acquired procedural knowledge about freezing.

A teacher joined this group as if she were an ordinary member. That is, she was engaged in the inquiry as the children were, but at the same time, she encouraged the children to continue their inquiry by showing interest in their ideas/motivation for knowing. For example, she permitted them to use any vessels and any places in the day care center they wished in order to examine their ideas. In addition, she sometimes took the role of a more capable peer when the peer interaction appeared to have come to a premature halt. For example, she stimulated children's thinking by giving a counterexample when the inquiry seemed to be about to stop because a majority of

children had accepted a wrong hypothesis.

Stages of Knowledge Acquisition

The processes of knowledge acquistion through peer interaction consist of cycles of four stages. A complete cycle comprises the following four stages, but there may be incomplete cycles as well ; one or two of the four stages, especially the third stage, is likely to be repeated ; the last stage of a cycle and the first stage of the following cycle sometimes overlap each other.

The first stage is characterized by the initiation of information seeking (or knowledge acquisition). Generally speaking, acqusition of knowledge is initiated by either epistemic curiosity (Berlyne, 1963 ; Hatano & Inagaki, 1971 ; Inagaki, 1982) or by the desire for inducing an event which people value in some sense, as in the case of alchemists. When these two motives are combined, the initation of information seeking must be accelerated. That is, when people are exposed to the non-occurrence of desirable state Y, contrary to their expectation, they are likely to be motivated to ask why, how, etc. and to seek further information.

We find a good example of this in "Making Ice." (See the 'Beginning' section in the appendix.) Here the joint arousal of the two motives contributed to the initiation of seeking further information. That is, the children desired to have a frozen swimming pool so that they could play on it, but they found that they could not always do it, since, to their unexpected disappointment, they had days without ice. This cognitive conflict was strengthened later by facing disagreement on the causes of freezing ; some children insisted that freezing was due to rain and others disagreed.

In the situation like this, we expect that children are likely to have such a question as "Why didn't it happen ?" When this type of question occur to them, we also expect they will either request an adult to give explanations, or continue the investigation by transforming it into a question such as "How can we make it happen ?" A question such as "How can we make it happen ?" is spontaneously asked by children in some cases ; in other cases it is asked intentionally by a teacher who wants the children to discover a new fact for themselves. Nagano (1970) insists that teachers should give young children the "manipulable" objective of producing the target phenomenon in order to motivate their scientific inquiry. In other words, teachers should ask such a question as "How can we make it happen ?" rather than why-questions in order to help children initiate the acquisition of knowledge. An utterance having the same function as this type of question is seen in 'Beginning' of "Making Ice", i. e., the proposal, "Let's try to make ice," offered by a child.

The second stage is that of the production of a number of hypotheses about the key question such as "How can make it happen?". That is, children are expected to produce hypotheses like "We can make it happen by doing X." The proponent of a hypothesis like "We can make it happen by doing X" may try to justify it on some ground, in order to make it persuasive to his/her peers. The following are seen as major justifications : a) justification based on the proponent's direct experience ; b) justification based on indirect experience, i. e., he/she has read or heard about it ; and c) deductive justification from his/her prior knowledge, e. g., meta-procedural knowledge. A concrete instance of the last category is a child's saying, "Plants need

sunshine in order to grow. The place by the fence is often in the sunshine. Therefore, if we plant a flower by the fence, it will grow well."

However, this does not mean that young children can always give such a justification. What are important here are that children can produce a number of hypotheses, and that some of them feel a certain hypothesis is so plausible that they consider it worth examining. Disagreement among children as to the truth of the hypothesis may even more strongly motivate its supporters to confirm it. On the contrary, when a majority of children come to accept a hypothesis, their inquiry may easily terminate at that point. One of the strategies which a teacher can use in this case is to give children a counterexample. We find a good example of such a strategy in "Making Ice". Here, seeing that a majority of children were about to agree to the idea that being placed inside prevented the water in the vessels from freezing, the teacher gave them a counterexample (See T2).

A reservation should be added : Hypotheses which children produce at this stage are expected to be different from the ones which adults produce in their scientific inquiry processes. That is, children rarely construct some explicit model involving mechanisms explaining the occurrence of observable event(s). Usually, their hypotheses are described in a procedural form. The child's utterance, "If we plant a flower in the sunshine, it will grow well", is a good example of it.

In "Making Ice" the second stage of the production of hypotheses is found several times. In some cases a hypothesis is implicit in that we can only infer its existence from what the children did and what they commented on it. It other cases a hypothesis is explicitly stated by children. A typical example of the former is found when children generated a hypothesis that some features of containers to hold water (particularly color and/or material) were critical. Before the children began experimentation, they did not state this hypothesis explicitly. However, we can infer that they had this hypothesis implicitly from their own behavior---they left a variety of containers filled with water---and utterances such as C11, "I could make ice in my bucket, but *Miho* couldn't, though *Miho* and I used the same kind of blue buckets." A good example of the latter, i. e., explicitly stated hypothesis, is seen in C20, "Let's leave the vessels in different places.", or C18, "First, I left my vessel inside. The ice I've got there was thin. Next day I left my vessel outside. I was able to get thick ice there. On that day the water in *Miho*'s vessel didn's freeze. I suspect *Miho* left her vessel inside." Children here seem to have had a "place" hypothesis, which regarded the place where containers were put as a critical factor.

The third stage of knowledge acquisition is that of experimentation. Children usually do not possess the scientific rigor of adults. There is only weak correspondence between a hypothesis to be examined and the experimental design in everyday inquiry by children. If a hypothesis is "If we do X, then we will get Y," the simplest test for children is to run an experiment by doing X all the time, without worrying about the control condition. As a matter of fact, however, some children who are against that hypothesis, will run an experiment by trying $\bar{X}$ (something other than X). Thus it becomes possible to compare the effects of X and $\bar{X}$ in the whole system. Although an ideal experimentation requires us to hold constant all the variables except X and $\bar{X}$, or

to change some variables systematically, children in fact are unlikely to control these variables. Consequently, the experimentation often contributes not only to confirm/reject a particular hypothesis but also to induce new questions. We see a good example of this in the experimentation based on the "rain" hypothesis in "Making Ice". That is, when the children were doing experiments according to the hypothesis that rain might be related to freezing, they encountered an interesting event, i. e., all the water in the same kind of vessels did not turn into ice with the same thickness, because they had failed to control the place variable. Although this experimentation confirmed the prediction that the water in the vessels froze even if it did not rain, at the same time it elicited a new question in the children, who failed to notice the difference of temperature between inside and outside. Thus their inquiry continued.

This third stage is also recognized several times in "Making Ice". A typical example is seen when children experimented by leaving their containers in various places, following the proposal of C20 involving "place" hypothesis. When the results of an experiment is found to be inconclusive, possibly another test will be run, usually adding refinements. Accordingly, when the children found that water in the same kind of vessels had not frozen in the same way, a more refined experiment where the place variable was to be held constant was done, as suggested by the proposal of C14, "Let's leave our containers in the same place." When the children found that no water in any vessels which had been put in the same place turned into ice, the same experiment was repeated, as C16, "Let's leave the vessels as they were once more." Needless to say, teacher's implicit encouragement would certainly contribute to having the experimentation continue. If the teacher had considered such experimentation unimportant or impossible in early childhood education, children's inquiry might well have been blocked out easily.

The fourth stage of knowledge acquisition is the collection of data and induction. Children reach a conclusion of their own through induction based on the results of the experiment (s). Two kinds of induction can be distinguished. One is schematic induction : Children derive a conclusion with confidence by applying their preexisting schema to incomplete data. A good example is seen in "Making Ice". Children there did experiments to confirm their "features of vessels" hypothesis, and left various vessels filled with water in the same place. When they found that only the water in a styrofoam vessel with a lid had not frozen, they were convinced, through this one observation, that the lid had prevented freezing (See the first four sentences in "Fourth Day" in the appendix). This is probably because it was consistent with their "shelter" schema ("Shelter reduces influence from outside."). The second type of induction is a cumulative one. This is primarily empirical induction based upon cumulative experience. The knowledge about conditions of freezing which children expressed in "Ninth Day" was a product of their cumulative induction.

This fourth stage of knowledge acquisition is also recognized several times in "Making Ice", following the experimentation(s). C8, "Now I understand. The water in vessels freezes even if it doesn't rain.", represents this stage. A new question sometimes occurs in parallel with the stage of data collection and induction about the old one. The original question is to examine whether or not doing X causes Y, but it can

be found that doing X in fact causes different Ys in terms of grade. Then children are likely to pursue a new question of what differentiates Y_1 from Y_2. If they can transform this question into such a form as "How can we make Y_1 and Y_2 happen?", this inquiry will proceed further. In a continuous inquiry process like this, investigation often goes on even if there is no difference between Y_1 and Y_2 in terms of practical value. A good example of it is seen in "First Day" of "Making Ice". At the beginning, children were oriented to make ice (Y), probably in order to use it in playing afterwards. Thus they were eager to confirm whether the water would turn into ice even if it did not rain. However, when they examined the result of the experiments in relation to the "rain" hypothesis, they found out the new fact that the water in some vessels turned into thick ice (Y_1), while the water in other vessels turned into thin ice (Y_2). This finding motivated them to know what factor contributed to the difference (See the utterances of C9 and C10). Then those children continued their inquiry ; they seemed to have an implicit hypothesis that features of vessels might be related to freezing. The inquiry which children were engaged in at this point possibly changed from usefulness-oriented, where making ice had some practical utility (as a means of playing afterwards), to knowledge-oriented (or epistemic), where knowledge was sought for its own sake. This change will have contributed to produce deeper understanding.

Notes

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Appendix—Making Ice

Beginning

Several 5–6–year-old children were playing by stepping on the frozen swimming pool in a day care center. This activity was initiated spontaneously by these children. A teacher joined them later.

C1 : The water of the swimming pool isn't frozen hard today. The surface ice is thin. We can't step on it. It was frozen hard both yesterday and the day before yesterday, so I thought it must be frozen today, too.

On the following morning the swimming pool had no ice at all. The children were discussing this with one another as follows :

1 C2 : Didn't the water of the swimming pool freeze because it didn't rain ?
C3 : No. It has frozen without rain.
C4 : Why didn't it freeze today, then ?
C5 : ……
C6 : It's strange.
C7 : Let's try to make ice.

2·3 Then, these children left a variety of vessels filled with water anywhere they liked before they went home. (Since other children who heard about the "experiment" for making ice, and were interested, joined the original group, about 13–14 children participated in this activity.)

First Day

Next morning they found that the water in almost all the vessels had frozen.

4 C8 : Now I understand. The water in vessels freezes even if it doesn't rain.
1 C9 : Look, Miss M (teacher), the ice in *Hayato*'s and *Miho*'s buckets is thin.
C10 : Why is their ice so thin ? [Although only *Hayato* and *Miho* had put their buckets inside, no children seemed to notice it.]

2·3 Then children decided to continue this activity of making ice. They left the containers filled with water when they went home. The containers chosen by them were varied : empty cans, bottles, jars, plastic and wooden buckets, styrofoam vessel, basin, etc.

Second Day

The water in the containers of all children except for three *(Miho, Takako,* and *Yoshinori)* froze. The ice in *Makoto*'s container was thick.

4 C11 : It's strange. I could make ice in my bucket, but *Miho* couldn't, though *Miho* and I used the same kind of blue bucket.
1 C12 : *Yoshinori* and *Kyosuke* used the same kind of jam jars, but *Yoshinori* couldn's make ice. [*Miho, Takako,* and *Yoshinori* had put their containers inside, but children did not notice that.]

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* Taken and translated from Motoyoshi (1979).
* C shows child's utterance ; T shows teacher's utterance.
* Numerals attached to C/T show the order of utterance.
* Numerals on the left side show the stages of knowledge acquisition.

C13 : It's puzzling, isn't it ?
2 C14 : Let's leave our containers in the same place.
3 Following C14's suggestion, children left their containers together at a corner of the porch.

Third Day

The water in the containers which had been at the porch did not freeze at all.
4 C15 : It's strange. I wonder why we couldn't make ice. I suspect it is due to the fact that all of us put our vessels in the same place.
C16 : Let's leave the vessels as they were once more.
3 This proposal was accepted by the other children. They left their containers put in the same place as they did the day before.

Fourth Day

The children were pleased to find that the water in nearly all the containers had frozen. However, one of the children, *Kayoko*, complained with a tearful face, "The water in my vessel didn't freeze." *Kayoko*'s vessel was a styrofoam one with a lid. When children found this fact, they concluded that the lid had prevented freezing.

C17 : The water in *Miho*'s and *Yoshinori*'s vessels froze today.
4 C18 : First, I left my vessel inside. The ice I've got there was thin. Next day I left my vessel outside. I was able to get thick ice there. On that day the water in *Miho*'s vessel didn't freeze. I suspect *Miho* left her vessel inside.
T1 : *Miho*, did you leave your vessel inside ?
C19 : I saw *Miho* putting her vessel on the locker every day.
T2 : I left my vessel inside of the front door, but you see, it is frozen.
2 C20 : Let's leave the vessels in differnt places.
3 Following C20's proposal, children left their containers in various places, such as behind a storeroom, at a sunshiny porch, on the south side of a henhouse, in a washroom, on the north side of the day care center building, in their playroom, and in a staff room.

Fifth and Sixth Days

3 It did not freeze at all on the first and second days after the children began to do this new "experiment".

Seventh Day

Only six vessels, which had been put on the north of day care center building, were frozen. The ice in one of them, *Makoto*'s can, was thick and hard.

Ninth Day

On the ninth day after children began to engage in the activity for making ice, they expressed their ideas on freezing as follows :

a) There are days when water in the vessels freezes and when it doesn't.
b) Even if water in the vessels left inside does not freeze, we cannot say that water outside will not freeze as well.
c) It is strange that the water in some vessels turns into thick ice, while in

4 others, thin.

d) The water in *Makoto*'s vessel always turned into thick ice. His vessel was a shallow cookie-can.

e) When we left the bucket full of water (outside), the water on the top froze, while the water at the bottom didn't. Thus the water at the bottom is warm, I suspect.

f) The rain was nothing to do with freezing. The water seems to freeze on cold days.

g) The water in *Kayoko*'s styrofoam vessel did not freeze hard, even when she removed the lid. It seems to be warm.