17 Two Courses of Expertise

Giyoo Hatano
Kayoko Inagaki

Several aspects of cognitive development can be conceptualized as processes of spontaneous expertise.[1] Starting with little or no documented declarative knowledge or rules, children—through accumulated experience—acquire domain-specific knowledge enabling them to solve various problems in the target domain. After briefly discussing the significance of this conceptualization, we shall propose three issues related to the processes of spontaneous expertise. These issues, we believe, are not only theoretically interesting in developmental research, but can be studied profitably through cross-cultural analysis.

What is significant about conceptualizing processes of cognitive development as processes of spontaneous expertise? It has been asserted that developmental or adult-child differences in cognition are similar to expert-novice differences (Brown & DeLoach, 1978). This would imply that adults and children differ primarily in the amount and structuredness of knowledge in the target domain; in other words, in explaining adult-child differences, maturational and/or domain-general cognitive variables are, at most, secondary. Thus, this assertion gives an answer to the question, "What develops?" It is domain-specific knowledge that develops.

To conceptualize the *processes* of cognitive development as those of spontaneous expertise goes a little further. It suggests an answer to the question, "How does it develop?" Undoubtedly, the processes of expertise are based upon the accumulation of experience, which consists largely of solving problems in a given domain. In achieving expertise, individuals, supervised by more capable members, solve increasingly complex problems in the domain, using relevant prior knowledge which is, in turn, gradually enriched and integrated. In Piagetian terminology (Piaget, 1950): a new problem situation is assimilated into preexisting knowledge; this results in accommodation of the knowledge. According to this conceptualization, the key concern in developmental research is thus, the analysis of relationships between problem solving and acquisition-integration of knowledge in a domain.

From Procedural to Conceptual Knowledge

Our first issue concerns the processes through which novices become adaptive experts—performing procedural skills efficiently, but also understanding the

meaning and the nature of their object. In comprehending the object's nature, what role is played by repeated practice in daily life of the procedural skills involved? This issue seems quite similar to the one Piaget (1976, 1978) attempted to examine, but as will be seen, there are important differences.

In any society, less mature members acquire a body of procedural knowledge, that is, decision-rules as well as executive strategies, along with the skills necessary for applying that knowledge. Both the knowledge and its attendant skills comprise an important part of the culture. They are useful to their possessor in solving frequently encountered problems, thus increasing his or her competence as a member of the society. Such skills are therefore performed repeatedly. In a familiar environment, people behave quite effectively with only procedural knowledge, even without understanding. Usually they acquire procedural knowledge and skills without undue difficulty, through direct observation, verbal instructions, corrective feedback, and/or supervision. In this way, knowledge is transmitted from culture to individual, though individual selectivity also operates in the process.

However, since human beings have an intrinsic motivation to understand, we assume they are dissatisfied with any procedural competence they might achieve; they also want to understand, that is, to find the meaning of the procedural skill. What is the distinction between the performance with and without such understanding? When do we consider that a skill is performed with understanding? It is when the performer can explain why it works, that is, verbalize the principle involved. Or it is, at the least, when he or she can judge, not only the conventional version of the skill, but its variations as appropriate or inappropriate and/or can modify it according to changes in constraints (Greeno, 1980).

These explicit and implicit forms of understanding seem possible only when the performer has more or less comprehensive knowledge of the nature of the object of the procedure and its surrounding "world." This knowledge gives meaning to each step of the skill and provides criteria for selection of possible alternatives for each step within the procedure. It may even enable the performer to devise new procedures and to make new predictions. We will term this, *conceptual knowledge.* One form of conceptual knowledge is the so-called mental model (Gentner & Stevens, 1983), with which people can run mental simulations and make predictions or explanations about an unfamiliar object or situation that extends beyond their experience. By constructing conceptual knowledge, individuals can go beyond the culturally given. Without it, when the original version of the skill appears to reach its limits of effectiveness, all that is possible is trial-and-error or empirical minor adjustment.

People may ask themselves why a skill works, or why each step is necessary after accumulated practice has freed them from monitoring the skill consciously. Questioning of this nature can be the initial step toward the constructing of the relevant conceptual knowledge, but by itself alone, it is insufficient. Two kinds of component knowledge are also needed.

First, the individual needs *data*, or empirical knowledge. He or she must observe covariations of variables, that is, corresponding changes between actions and consequences or among dimensions of consequences. Variations in key variables may be produced "naturally"—by factors beyond intended control—or "socially," in a collective enterprise of performing the skills. Otherwise, people must intentionally vary the procedure to collect the data necessary for construction of conceptual knowledge. Said differently, they must examine versions of the skill other than the conventional one, an option which is "risky," to successfully solve the problem.

Second, they need to have a *model*—or preconceptual knowledge—even if only a tentative and implicit one.[2] Without this model, it is impossible to determine what variables are to be chosen for consideration from among an almost infinite number of candidates. A model may be obtained primarily through perception, as a somewhat vague "image" of the object—what it is like. It may also be derived indirectly, especially when mechanisms are invisible, on the basis of its functions or reactions to external stimulation. In the latter, it is often borrowed from another domain through analogy. Prior knowledge of constituent parts, if available, is also used in this derivation.[3]

These two types of component knowledge are reciprocally selective: the observed data suggest what model should be adopted, and the adopted model constrains what kind of data are to be observed.

It is likely that a farmer, starting with conventional farming skills, will acquire much conceptual knowledge about plants by observing "naturally produced" covariations while growing rice or corn. Because of this knowledge, tentative though it is, an experienced farmer can deal effectively with various changes in constraints, like unusual weather or plant disease. Eventually, the farmer may even serve as a consultant for less experienced farmers, and as such, can be legitimately called an adaptive expert (Hatano, 1982a).

Similarly, children may sometimes ask, while performing a procedural skill and receiving feedback: "How does A lead to B?" "Why is doing X necessary to produce Y?" (Karmiloff-Smith & Inhelder, 1975). As Condry & Koslowski (1979, p. 246) put it, a child, having found regularity, "seeks to know why and how." In other words, he or she looks for "causal explanations for the way the world is organized." From these questions, the child is likely to construct conceptual knowledge. Motoyoshi's observation (1979) suggests that children can incorporate observed data into a model, even when they cannot see the inside: after accumulated experience in attempting to grow a flower and then comparing her results with her friends', a 5-year-old girl stated: "Flowers are like people. If flowers eat nothing, they will get weak of hunger. If they eat too much, they will get sick." (p. 136)

To summarize, it can be assumed that people—children are no exception—can construct corresponding conceptual knowledge by performing a procedural skill, and with that conceptual knowledge they can be flexible and adaptive, for example, they can "invent" other procedural knowledge.

Do we overestimate children's capacity, since Piaget (1976, 1978) demonstrated a delay of several years between the guided, successful solution of a problem and understanding how and why the solution procedure works? We do not think so. His findings will be replicated if we give children novel, nonsignificant problems and adopt a rigorous criteria for assessing their understanding (for example, stating coherent justifications according to formal logic). What should be emphasized here is that even young children can construct some conceptual knowledge through repeated practice of a procedural skill in a "meaningful" context. Once obtained, this conceptual knowledge can not only invest the procedure with meaning (the how and the why), but it also enables children to make predictions in unfamiliar situations and to invent new strategies.

In a sense, what we have formulated here represents an attempt at a revival of the Piagetian spirit. Though we have placed greater emphasis on the constraints of eco-social settings and on the domain-specificity of cognitive competence, two of his basic ideas are intact. The first is that human beings have an intrinsic motivation for understanding; the second is that an important part of knowledge acquisition is endogenous; that is, achieved through reflexive abstraction. It is indirectly dependent upon external feedback, which serves only as a cue for interpretation, whereas internal feedback is brought about by reorganizing pieces of prior knowledge. Therefore, studying this first issue of adaptive expertise may shed light on an often-neglected aspect of Piagetian theory.

Since some procedural knowledge and skills are specific to a particular culture or subculture, it should be rewarding to use cross-cultural comparison to examine what conceptual knowledge results from practice in a particular culture-specific skill.

A promising attempt at this has been studies examining whether repeated application of culture-specific skills would result in the enhanced acquisition of substance-weight conservation of clay, an aspect of conceptual knowledge about the object of these skills (Adjei, 1977; Price-Williams, Gordon & Ramirez, 1969; Steinberg & Dunn, 1976).

It would also be interesting to examine whether children's spontaneous process of constructing conceptual knowledge is universal across cultures. Similarities in thinking have frequently been observed among children in a variety of cultures and between children and primitive people; this suggests a universal process is involved. On the other hand, historical differences between western and Japanese science suggest there can be different routes to the elaboration of the conceptual knowledge we call science. Although physics, with its atomistic and mechanistic ideas, has played a central role in western science, Japanese endogenous science evolved until the Meiji Restoration, with medicine, which was holistic and vitalistic, as its core (Yasunaga, 1976). Children too may construct different conceptual knowledge according to the availability and the conspicuousness of models in their culture.

Generalized Consequences of Routine Expertise

Adaptive expertise is not the only course of spontaneous development, however. Sometimes, in solving a large number of problems, people learn merely to perform a skill faster and more accurately, without constructing or enriching their conceptual knowledge (even after this might be possible because the procedure had become automatized). For example, many amateur gardeners have repeatedly grown Saint Paulia flowers as prescribed in a greenhouse, where both temperature and humidity can be automatically controlled, without understanding the nature of these flowers, the conditions under which they grow best, or the contents of the fertilizers. Our lives are filled with procedures we carry out simply to get things done; if we repeat them hundreds of times, we can become quite skillful at them. However, our skill is useful only as long as the object and its constraints are constant, that is, the same set of materials and devices is available. Thus, we may become routine experts, but not adaptive ones; routine experts are outstanding in speed, accuracy, and automaticity of performance but lack flexibility and adaptability to new problems. Nevertheless, people unhesitatingly call them experts, since their procedural skills are highly effective for solving everyday problems in a stable environment.

Clearly, even young children can become routine experts. The processes of routine expertise have been fairly well conceptualized (Anderson, 1981). We propose, therefore, that another challenging issue to study is not the processes of routine expertise themselves, but their "generalized consequences."

Two examples of such consequences are found in the studies of abacus operation and the processing of *kanji*, conducted by Hatano and his associates, which we shall describe next.

It is generally agreed a procedural skill is often efficient but only for a limited type of problem. This is mainly because the information embedded in the skill cannot be easily recombined to form other procedural skills (Rumelhart, 1979). However, practice in a procedural skill will facilitate the development of other procedural skills in the same domain. Thus, it will have some generalized consequences by transfer of training in the classical sense, that is, through shared components. We found that after-school training in abacus made third graders' paper-and-pencil addition-subtraction of multidigit numbers faster and more accurate primarily through the shared component skills of basic computation (for

example, use of the number facts of single-digit addition and subtraction, and of complementary-numbers-to-10) (Hatano & Suga, 1981). Though this practice did not improve pupils' understanding of principles of carrying or borrowing, it reduced the number of "bugs," that is, the consistent application of wrong algorithms, as well as careless errors in paper-and-pencil computation. This probably occurred because these learners had little difficulty in executing the right procedure.

Moreover, routine expertise in a procedural skill often produces as byproducts strategies or consolidated sequences of behaviors by which the skill can be even more efficiently performed. These byproducts are essentially cultural learning sets. Thus, routine experts often show a capacity remarkably different from that of ordinary people in tasks which, though apparently very different, induce these sequences of behaviors. Scribner and Cole (1981) demonstrated that literacies developed and used in different contexts tend to produce a correspondingly differentiated pattern of cognitive competence. It has also been shown that experienced readers of Japanese can quickly infer the meaning of unfamiliar *kanji* compound words appearing in a discourse by combining prototypal meanings of the component *kanji*. This is because readers are so accustomed to retrieving the meaning directly from *kanji* and relying on compounding schemata (Hatano et al. 1981). A study still in progress suggests this skill for inferring meaning can be generalized to "artificial" words, components of which are new, experimentally introduced symbols with verbally given prototypal meanings.

Finally, routine expertise may produce new mental devices convenient for performing a given task. Abacus experts have interiorized the operation; thus, they can calculate without an abacus as accurately as, and often faster than, with it (Hatano et al. 1977). Grand experts of this abacus-derived mental arithmetic have a mental abacus of an expanded size on which they can represent a number of many digits. We found that such grand experts can rapidly reproduce a series of 15 digits either forward or backward. It might be added that these experts' span of memory for English alphabet letters or for names of fruit is not different from 7 ± 2. Also, their memory for digits is stable, and partially compatible with verbal input and output, but vulnerable to visuo-spatial interference (Hatano & Osawa, 1983). They still hold digits in working memory, not in the rehearsal buffer but in visuo-spatial storage, and do not transmit them to long-term memory. By this powerful mental device of representation, they can mentally calculate a series of large numbers in an algorithmic fashion. A recent developmental study (Hatano, Amaiwa & Shimizu, 1984) demonstrated that even lower-intermediate abacus operators, who can mentally add and subtract numbers of 2 to 3 figures only, rely to some extent on a mental abacus for memorizing digits. As abacus operators become experts at abacus and mental calculation, the mental abacus plays an increasingly dominant role.

In sum, routine expertise may, in fact, produce more or less "generalized consequences," not through understanding, but through well-established patterns and modes of processing. It should prove rewarding to examine, by cross-cultural comparison, what generalized consequences are brought about by practice in a culture-specific skill, which is necessitated by the eco-social environment or fostered by cultural tradition. Since it takes thousands of practice hours to become a grand expert, it is impossible to assign subjects randomly to either the experimental or the control condition. Therefore, cross-cultural comparison is often the only realistic research strategy. The more closely we observe the target skill and context for its use, the more likely we will be to assess the subtle characteristics of its experts, that is, the generalized consequences of the skill.

Factors Differentiating Adaptive and Routine Expertise

If, then, there are two courses of expertise, adaptive and routine, what factors differentiate them? With the present scanty empirical evidence, a comprehensive answer is impossible, but we would like to discuss our speculations in greater detail, deriving our basic ideas from Piaget (1950). As has been discussed, Piaget believed human beings are intrinsically motivated to understand the world. At the same time, he pointed out that, to understand, it is necessary to examine systematically the effects of variations in action upon outcome. This can be achieved by either actively manipulating certain variables or observing naturally occurring variations. However, we know that people are not always engaged in such active experimentation. What encourages someone to engage in such experimentation? We would like to propose three factors.

The first concerns the nature of the object which the procedural skill deals with and the constraints for successfully obtaining the desired outcome. More specifically, it concerns to what degree such a system of object and constraints contains built-in "randomness." If a skill concerns a "natural" object, a variation in critical parameters, which often occurs because of the system's built-in randomness, may make the original version of the skill ineffective, thereby motivating some modification of the skill. In other words, the person applying the skill has many opportunities for observing the effects of modification of the skill on the outcome. Consequently, repeated application of the procedure with variations is likely to lead to adaptive expertise. On the other hand, if the system the procedural skill deals with is highly standardized or is without built-in randomness, there is no necessity for even minor modification of the skill. Here, repeated application of it without variation is unlikely to lead to adaptive expertise. For example, in traditional agriculture, because of individual differences in the nature of a plant (for example, growth rate, vulnerability to disease) and weather conditions that change to some degree from year to year and are, moreover, beyond human

control, people are obliged to modify their skill, depending on feedback received during the performance of it. Similarly, in preparing home-cooked meals, the chef's available ingredients may not always be the ones listed in the recipe. In short, people need to adapt a procedural skill according to the amount or kind of materials or devices available to them at the time of performance. In these instances, the performer will probably acquire conceptual knowledge, that is, the how and the why of each step. However, in modernized agriculture, such as greenhouse plant growing, where performers can choose a highly specified variety of plants and easily control weather conditions like temperature and humidity, skill flexibility is not essential. In the same way, cooking with an automatic device (for example, an electronic oven) and a detailed recipe involving precise quantification may ensure a standard dish, but people doing it will have less opportunity to acquire the related conceptual knowledge. As these examples show, modern technology, which aims at reducing built-in randomness in the system, by no means facilitates the acquisition of conceptual knowledge. If we can empirically confirm the above prediction in cross-cultural studies between technologically more advanced and less advanced societies, it may have a strong social impact.

The second factor concerns the context in which the procedural skill is used. When the results obtained through performing it have no vital importance or usefulness, performers tend to produce minor variations in procedural skill and to examine their effects, often playfully. That is, they are willing to engage in active experimentation which, in turn, creates a greater possibility of acquiring conceptual knowledge. In contrast, when a procedural skill is performed primarily to obtain rewards, people are reluctant to risk varying the skill, since they believe safety lies in relying on the "conventional" version. This observation has been supported, though indirectly, by recent studies suggesting the expectation of reward, either tangible or symbolic, decreases quality of performance and intrinsic motivation (Lepper & Greene, 1978). In reviewing these studies, Inagaki (1980) suggests that expectation of reward may prevent learners from understanding things deeply. It changes the "goal structure" of the activity, and thus leads learners to shift from "heuristic" strategies, such as "examining possibilities of alternative solutions" or "seeking a more universal solution beyond the present successful one," to "algorithmic" strategies, ensuring steadier and often quicker solutions within a given time. It is suggested, then, that to maximize an expected external reward a learner may adopt an orientation toward success or efficiency rather than toward understanding.

Inagaki and Hatao (1984) confirmed that when college students, expecting an external evaluation of their performance, were required to translate a letter from English into Japanese, they adopted a "safety strategy." These students spent more time in translation and more frequently checked the dictionary for uncertain words than did control students who had been given no such expectation. Yet, despite the longer time spent, the "expectant" group elaborated less on expressions which required inference by them to be fully understood. The study suggests that the subjects tended to stay within the imposed task of translation, instead of proceeding toward coherent interpretation of the content of the letter. It also suggests that the externally rewarding performance—a frequent occurence in schools—may prevent students from seeking the understanding through which conceptual knowledge is acquired.

The third factor concerns the degree to which understanding a system of the objects-constraints of procedural skills is valued by reference group members. A culture, where understanding the system is a goal, encourages individuals in it to engage in active experimentation. That is, they are invited to try new versions of the procedural skill, even at the cost of efficiency. They are also often required to explain the appropriateness of the skill, largely in relation to others, but sometimes to themselves. In explaining, individuals tend to try to select, integrate, and elaborate potentially relevant pieces of preconceptual knowledge, probably relying on mental experimentation. By contrast, a culture, which highly values the prompt performance of a procedural skill and its outcome, discourages individuals to seek explanations or examine new variations in the skill. Such a culture regards asking why or forming corresponding conceptual knowledge through experimentation as extraneous or even detrimental to performance efficiency. Hunt and Love (1972) suggest that few great mnemonists—like their subject "VP"—can be found in American society, where asking why as opposed to practicing memorizing is encouraged. We suggest accumulated practice of procedural skill is likely to lead to adaptive expertise under an understanding-oriented culture, whereas it is likely to result in routine expertise under a promptitude-oriented culture. A culture, comprising the shared beliefs of the "developed" people in it, would be internalized by its "developing" members because their metacognitive goals of knowing would be acquired through joint activities with developed members (see Wertsch, 1979).

Since Japanese schools and homes are said to be efficiency oriented rather than understanding oriented (Hatano, 1982b), it will be interesting to examine whether Japanese children are in fact inferior to members of an understanding-oriented culture in the flexibility and the adaptability of their procedural knowledge.

Footnotes

1. We recognize that there are other courses of expertise. For example, one may proceed from a well-defined set of declarative knowledge or rules to proceduralization and automatization (see Anderson, 1981).
2. This is, in other words, the structure which can integrate the observed covariations. We avoid the term *structure* because it may be interpreted to connote a general one like Piaget's structure of coordination.

3. There can be, therefore, intermediate stages in the construction of conceptual knowledge, where pieces of partial knowledge are not well integrated into a whole or where different models coexist. For example, a person may know that object A is similar to object B in its construction without being able to specify the difference between the two; he or she may know that it has parts a and b without grasping how they are connected.

References

Adjei, K. (1977). Influence of specific maternal occupation and behavior on Piagetian cognitive development. In P. R. Dasen, (Ed.), *Piagetian psychology: Cross-cultural contributions* (pp. 227–256). New York: Gardner Press.

Anderson, J. R. (Ed.) (1981). *Cognitive skills and their acquisition.* Hillsdale, N.J.: Lawrence Erlbaum Associates.

Brown, A. L., & DeLoache, J. S. (1978). Skills, plans and self-regulation. In R. Siegler (Ed.), *Children's thinking: What develops* (pp. 3–35). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Condry, J., & Koslowski, B. (1979). Can education be made intrinsically interesting to children? In L. G. Katz, (Ed.), *Current topics in early childhood education*, Vol. II, pp. 227–260. Norwood, N.J.: Ablex.

Gentner, D., & Stevens, A. L. (1983). *Mental models.* Hillsdale, N.J.: Lawrence Erlbaum Associates.

Greeno, J. G. (1980). *Forms of understanding in mathematical problem solving.* Paper presented at the 22nd International Congress of Psychology, July, 1980, Leipzig.

Hatano, G. (1982a). Cognitive consequences of practice in culture specific procedural skills. *Quarterly Newsletter of Laboratory of Comparative Human Cognition, 4*, 15–18.

———. (1982b). Should parents be teachers too? A Japanese view. *Dokkyo University Bulletin of Liberal Arts, 17*, 54–72.

Hatano, G., Kuhara, K., & Akiyama, M. (1981). Kanji helps readers of Japanese infer the meaning of unfamiliar words. *Quarterly Newsletter of the Laboratory of Cognitive Human Condition, 3*, 30–33.

Hatano, G., Miyake, Y., & Binks, M. G. (1977). Performance of expert abacus operators. *Cognition, 5*, 57–71.

Hatano, G., & Osawa, K. (1983). Digit memory of grand experts in abacus-derived mental calculation. *Cognition, 15*, 95–110.

Hatano, G., & Suga, Y. (1981). *Abacus learning, digit span and multi-digit addition/subtraction skills among 3rd-graders.* Paper presented at the American Educational Research Association Annual Meeting, April, 1981, Los Angeles.

Hatano, G., Amaiwa, S., & Shimizu, K. (1984). *Formation of "mental abacus" for computation and for memorizing digits: A developmental study.* Paper presented at the

American Educational Research Association Annual Meeting, April, 1984, New Orleans.

Hunt, E., & Love, T. (1972). How good can memory be? In A. W. Melton & Martin (Eds.), *Coding processes in human memory.* (pp. 237–260). Washington, D. C.: Winston.

Inagaki, K. (1980). Effects of external reinforcement on intrinsic motivation. *Japanese Psychological Review, 23,* 121–132. (In Japanese with an English summary)

Inagaki, K., & Hatano, G. (1984). *Effects of external evaluation on reading comprehension and intrinsic interest.* Paper presented at the American Educational Research Association Annual Meeting, New Orleans.

Karmiloff-Smith, A., & Inhelder, B. (1975). If you want to get ahead, get a theory. *Cognition, 3,* 195–212.

Lepper, M. R. & Greene, D. (Eds.) (1978). *The hidden cost of reward.* Hillsdale, N.J.: Lawrence Erlbaum Associates.

Motoyoshi, M. (1979). *Essays in education for day care children: Emphasizing daily life activities.* Tokyo: Froebel-Kan. (In Japanese)

Piaget, J. (1976). *The grasp of consciousness.* London: Routledge & Kagan Paul.

———. (1978) *Success and understanding.* London: Routledge & Kagan Paul.

———. (1950). *The psychology of intelligence.* New York: Harcourt Brace & World.

Price-Williams, D. R., Gordon, W., & Ramirez, M. (1969). Skill and conservation: A study of pottery-making children. *Developmental Psychology, 1,* 769.

Rumelhart, D. E. (1979). *Analogical processes and procedural representations.* CHIP Report No. 81. Center for Human Information Processing, University of California, San Diego.

Scribner, S., & Cole, M. (1981). *The psychology of literacy.* Cambridge, Mass.: Harvard University Press.

Steinberg, B. M., & Dunn, L. A. (1976). Conservation competence and performance in Chiapas. *Human Development, 19,* 14–25.

Wertsch, J. V. (1979). From social interaction to higher psychological processes: A clarification and application of Vygotsky's theory. *Human Development 22,* 1–22.

Yasunaga, T. (1976). *Ando Shoyeki.* Tokyo: Heibon-Sha. (In Japanese)

A Series of Books in Psychology

Child Development and Education in Japan

Edited by
Harold Stevenson
Hiroshi Azuma
Kenji Hakuta

W. H. Freeman and Company
New York