Bridging to The Unknown:
A Transition Mechanism in Learning and Development

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Outline

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How are new abilities created out of existing, less advanced abilities? This question has puzzled researchers for centuries. Various answers have been suggested, yet the mechanisms underlying development have remained enigmatic. In this chapter, we analyze and demonstrate a process called bridging that provides a specific answer to the fundamental question of how more powerful structures can be achieved on the basis of less powerful ones.

Bridging is a process of leaping into the unknown by inserting marker shells that indicate targets for development and learning (Granott,1993a,1994, Granott & Parziale, 1996). The marker shells serve as place-holders that people use to direct their own learning and development toward achieving these targets. A shell is like a formula in mathematics, in which the variables represent an unknown whose values can be later defined. Bridging operates as an attractor in dynamic systems and pulls development toward more advanced, relatively stable levels. People use bridging by creating partially defined shells that mark future skills to be constructed at higher knowledge levels. The shells do not contain the relevant knowledge yet, but they outline it. The shells serve as scaffolds that guide the construction of new knowledge by providing a perspective for processing new experiences. A bridging shell serves as a dynamic attractor after its initial emergence in real-time activities within context.

We suggest that bridging is a transition mechanism that people use spontaneously at a wide range of ages. Bridging occurs through self-scaffolding as well as other-scaffolding, within individuals and between people in social interaction. It takes several forms with a similar underlying mechanism, all of which are characterized by setting tentative targets for an unknown skill to be constructed at a developmental level higher than the level of the person's current activity. That is, in bridging, a person functions at two levels simultaneously: the lower level of the ongoing, actual activity and the higher level of the bridging shell that points to future learning..

What Creates Development? Views about Transition Mechanisms

Understanding how development is created is an old-age challenge. Researchers have tried to explain it in different ways. Sociohistorical and cultural approaches highlight the ways the social context with its signs, tools, and practices influence development. (e.g., Cole, 1988; Leontiev,1981; Rogoff et al.,1993; Vygotsky, 1978; Wertsch,1985). Piaget's theory accounts for the development of new structures by constructs such as assimilation, accommodation, equilibration, and reflective abstraction (e.g., Piaget, 1970, 1985). The extreme nativist approach attributes development to maturation of innate abilities (e.g., Gesell, 1940), especially in language development (e.g., Chomsky, 1975, 1980; Fodor, 1975). Today, many researchers agree that both genetic constitution and children's experiences combine forces to create development (e.g., Gottlieb, 1991; Lerner, 1991; Scarr, 1993).

Recently, aspects of innate principles have been interwoven with new approaches to study development, especially in dynamic systems and connectionism (e.g., Elman etal., 1996; Thelen & Smith, 1994). Applications of dynamic systems theory to the study of development suggest processes of self-organization within a developing system that serve as a mechanism of developmental change. According to dynamic system theory, new forms emerge as a result of nonlinear interaction among the system's components. In development, new behavior is created through nonlinear assembly of multiple components related to the organism and its environment (Lee &

Karmiloff-Smith, this volume; Lewis, this volume; Thelen & Corbetta, this volume; Thelen & Smith, 1994; van Geert,1998a). Self-organization creates new patterns and forms. Due to its self-organization, the system may settle in a new, more stable pattern -- an attractor -- which seems to attract the system to it.

Several researchers use dynamic modeling to explain and simulate developmental processes (e.g., Case et al., 1996; Fischer & Bideli, 1998; Fischer & Rose, 1994; Smith & Thelen, 1993; Thelen & Smith, 1994; van Geert, 1991, 1994, 1998b). Considerable work is based on connectionism and modeling of development after neural network growth (e.g., Elman et al., 1996; Grossberg, 1987; MacWhinney & Leinbach, 1991; Rumelhart & McClelland, 1988) or other computational models (e.g., Klahr, 1992; Simon & Halford, 1995). Models can provide rich hypotheses that can later be studied in human behavior.

In the area of problem solving, many researchers explain the construction of new knowledge in terms of hypothesis testing. The classical theories of learning as hypothesis testing focus on specific contexts, such as behaviorist models of animal learning (Krech, 1932; Tolman, 1948), models of learning as scientific problem solving (Duncker, 1945; Klahr, Fay, & Dunbar, 1993; see also Inhelder & Piaget, 1955/1958), or problem-solving models based on computer programs (Newell & Simon, 1971). Analyses of hypothesis testing examine learning as testing one or more hypotheses until finding a correct solution.

The gamut of the approaches for studying and explaining developmental transitions combines to make important contributions in diverse ways. However, the source of developmental change is still enigmatic. Some answers lead to reformulation of new questions about the sources of development. For instance, what are the ways and the rules under which innate abilities mature? Or, what are the specific mechanisms that assist the individual's development through social interaction? Alternatively, how can the processes of assimilation, accommodation, and equilibration be specified to allow their operational identification in real time activities? Or, how are hypotheses formed? The solutions of dynamic systems, neural networks, and other computational theories provide a necessary structural background, suggest processes and concepts that explain development, and formulate algorithms to model it. However, rarely do they show these solutions in actual, real time activities related to higher cognitive functions.

In this chapter, we specify a process that people use at different ages for developing new, higher-level knowledge out of previous, lower-level knowledge. We define operational tools that identify empty shells of missing knowledge and explain how the shells operate as a developmental transition mechanism with the characteristics of an attractor in dynamic systems. Examples of actual activities demonstrate the transitions that people make from missing knowledge, indicated by empty shells, to full-blown, well-defined knowledge.

People often construct their own shells or scaffolds, which is the focus of our analysis; but bridging also occurs in situations where a more knowledgeable person suggests bridges or scaffolds for a less knowledgeable one. Bridging has much in common with processes observed in expert-novice interactions, such as parent-child and teacher-student (e.g., Newman, Griffin, & Cole, 1989; Vygotsky, 1978). For example, in guided participation, parents use techniques to scaffold the knowledge construction of their children (Rogoff, 1990). They build bridges from known to new, linking new knowledge to what their children already know. Caregivers create bridges between their own and their child's knowledge through mutual involvement and by orienting the child to new information (Rogoff, Mistry, Goncu, & Mosier, 1993). Similarly, teachers and educators scaffold their students' learning by relating new material to what their students have already studied, creating a bridge between the known and the new to facilitate further learning. Case and his colleagues devised a teaching technique that deliberately created a conceptual bridge between children's current level of functioning and a subsequent, more advanced level. Using this technique, teachers designed an animation script, much like a sequence of cartoon drawings. The animation provided external referents, representing the students' current cognitive structures. After practice, when the students familiarized themselves with the cartoon drawings, the teacher expanded the cartoon sequence with referents for more advanced structures, facilitating the students' progress to a higher cognitive level. In this way, the teacher supported students' developmental transitions (Case, 1991; Case & McKeough, 1990).

The bridging analysis that we present here likewise connects known to new, yet it specifies microdevelopmental processes that have not been suggested in the previous literature. (1) Bridging highlights spontaneous ways in which people *self-scafold their own knowledge.* Scaffolding by a more knowledgeable person is less puzzling than the emergence of knowledge without guidance. In bridging, people spontaneously construct self-scaffolding shells for their own learning and development. (2) Bridging indicates the process from the perspective of the developing person. It focuses on the way in which people create for themselves shells of developmental levels not yet constructed. (3) Bridging occurs in diverse commonly-used forms that are readily observable in children and adults' activities. These bridging forms are based on simple, prevalent, everyday techniques, yet they facilitate significant construction of new, higher-level knowledge.

The bridging mechanism creates transitions that are tentative and partial. Because of their fleeting, under-defined nature, special attention is required for developing methods that can capture these transitions.

Facilitating the Identification of Transition Mechanisms in Development

Analysis and identification of developmental transitions can be facilitated in several ways: first, by using methods that give access to the process of change; second, by distinguishing between aspects of activity with different, simultaneous developmental levels; third, by analyzing activities within their social and environmental context; and fourth, by devising methodologies to allow reliable coding of partial, under-defined achievements.

1. Getting Access to Processes of Change: Analyses of long-term development, based on longitudinal or cross-sectional methods, compare abilities at different ages. These analyses compare static states (the "before" and the "after") and can indicate global developmental trends, but cannot capture how change occurs.

In contrast, several recent approaches focus on the developmental process itself, such as those used by researchers in this volume. From the early history of the study of development, research on microdevelopment (development during short time span) analyzed processes of change (Duncker,1945; Werner, 1948,1957). Detailed descriptions of developmental processes have been especially common in language development (e.g., Bowerman, 1989; Brown, 1973; Dromi, 198711996). Studies that use the microgenetic approach, with dense sampling of data, are especially promising when focusing on a specific period of change (Siegler & Crowley, 1991). Recent research on microdevelopment has produced new findings that highlight variability in developmental processes. Many researchers have found that within a short time span, people shift between more and less advanced strategies or knowledge levels (e.g., Fischer & Bidell, 1998; Fischer & Granott, 1995; Fischer & Yan, this volume; Goldin-Meadow, Nusbaum, Garber, & Church, 1993; Goldin-Meadow & Alibali, this volume; Granott, 1993a,1998a, this volume; Kuhn, this volume; Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; Miller & Aloise-Young, 1995; Schauble, 1990,1996; Siegler, 1996, this volume, Siegler & Jenkins, 1989; Smith & Thelen, 1993; Thelen & Smith, 1994, van Geert, 1994, this volume). Analysis of microdevelopment is instrumental for illuminating such processes of change in development and can illuminate the process of learning (e.g., Gelman, Romo, & Francis, this volume; Parziale, this volume). By following microdevelopmental processes instead of focusing on static states, researchers can observe the characteristics of the process of change and highlight its key attributes (Miller & Coyle, 1999).

2 Differentiating between Aspects of an Activty with Different Developmental Levels: People often function at multiple levels concurrently, especially in relation to indicators for different aspects or components of an activity. Analysis of one indicator may show developmental progress, while other indicators may not. In such cases, identifying change depends on differentiation between developmental indicators. For example, in a study of collaborative solutions of unfamiliar problems, participants operated on different levels simultaneously, constructing multiple concurrent developmental paths (Fischer & Granott, 1995; Granott, 1993a,1998a, this volume).

Different aspects of the same task showed a different developmental picture. Initially the participants showed high-level skills related to communication and low-level skills related to understanding the new problem. During their activity, their communication levels showed no significant developmental trend while their understanding showed substantial growth. Without differentiating between aspects of the activity, it would be impossible to capture this change. Process-oriented analyses often indicate that people operate simultaneously on different levels (e.g., Damasio & Damasio, 1992; Fischer & Ayoub, 1994; Goldin-Meadow & Alibali, this volume; Kuhn et al., 1995; Marcel, 1983; Siegler, 1996, this volume; Thelen & Corbetta, this volume, Thelen & Smith, 1994), highlighting the need to differentiate aspects of the activity.

Bridging shows the importance of recognizing multiple levels of operation and thinking. Bridging cannot be identified under the assumption that people function at a single level, because bridging itself includes both lower and higher levels- a lower actual level and a higher target level for the current task. Therefore, analysis based on the assumption of a single level cannot identify transition mechanisms like bridging.

3. Analyzing Activities within Context: Developmental research often focuses on individual participants. However, in real life, behaviors are embedded in context. Interactions with others are part of the developmental reality (e.g., Bronfenbrenner, 1993; Granott, 1993b, 1998b; Mead, 1934; Rogoff, 1990; Vygotsky, 1978). Social interactions affect developmental progress (Fischer, Bullock, Rotenberg, & Raya, 1993, Granott, 1993b, 1998b). Analysis of single individuals will not capture change that evolves through interaction.

Moreover, studying interactions among partners gives a natural access to analyzing how change occurs (Granott, 1993a, 1998b). During collaboration, partners spontaneously share with each other their thoughts and understanding. They talk about their observations, formulate hypotheses, and offer explanations. Their communication provides rich data that exposes thinking and developmental change (Granott, 1993b; Radziszewska & Rogoff, 1988).

To account for this process, (Granott, 1998b) defined a collective unit of analysis-an ensemble. The ensemble is the smallest group that co-constructs knowledge within a specific activity-context. The ensemble can be of different sizes-a dyad, triad, or a larger group. What qualifies a group as an ensemble is that knowledge is a product of the interactive process between the partners. What gives meaning, guides, and constrains the ensemble's activity is the specific context of its operation. Analyzing ensembles' activities, therefore, is not only more ecologically valid, but also more promising for identifying transition mechanisms in development.

<u>4. Identifying Partial, Under-Defined Steps</u>: Transitions in development occur through tentative, undetermined steps. They are partial and clumsy, like a child's first steps. Identifying these transitions requires the use of analytic methods that capture ambiguous, partial steps. Traditionally, coding creates clearly distinct categories, for example for stages or strategies. Researchers devise a coding manual with well-defined criteria for each category. An activity is placed into a category when it meets the category's criteria. Activities, then, are coded as either showing an attribute or not. This practice was developed to assure validity and reliability in coding. However, transitions and partial steps between categories cannot be captured in this way and are ignored

and omitted from the analysis. This method discards the exact data that may contain developmental transitions.

To overcome this difficulty, coding systems that define transitions in an objective, reliable, and valid way have to be developed. Such coding systems focus not only on stages, levels, or categories, nor do they merely identify transitions with a global label. Instead, they identify transitions, specify the process of the transitions and the contents of change, code these transitions, and include them in the data. Such coding systems can facilitate the analysis of change and developmental transition mechanisms in development.

Identifying and Analyzing Bridging. By structuring an experiment and developing a method of analysis that uses the four conditions specified above, Granott (1992,1993a) discovered the mechanism of bridging in a study on adults' collaborative scientific inquiry and problem solving. Parziale identified the same mechanism in middle-school children's collaborative processes of scientific problem solving (Parziale, 1997, this volume). In both studies, we used the same principles. (1) We focused on processes rather than states by targeting real-time microdevelopment. A whole microdevelopmental process was continuously videotaped to capture change. (2) We distinguished between different aspects of the activity and analyzed microdevelopment of each aspect separately. (3) The activity was collaborative and was studied in relation to its context Analysis of the participants' activity and conversations gave us access to the microdevelopment of their understanding. (4) Within each study, the coding system defined partial transitory steps as bridging shells. The analysis was based on Fischer's (1980) skill theory and captured partial constructions between skill levels. These transitions were classified and defined in an operational way that showed high reliability between coders.

Although in the two studies the participants' ages and the tasks were different, we found in both the same transition mechanism of bridging. Moreover, the bridging processes of adults and children were similar to processes documented and analyzed in the study of infants in other research, which we describe later. This similarity and the findings of bridging at different ages suggest that bridging is a general transition mechanism that operates across the life span.

What is Bridging?

Like an attractor in dynamic systems, bridging indicates a relatively stable state toward which the system gravitates. Three main attributes characterize and define the process of bridging. (1) It is a partial, transitional step that does not constitute a developmental level by itself. Instead, it denotes a search for new knowledge, giving a glimpse of new development. (2) Bridging operates with future, not yet constructed knowledge. It outlines a target level, albeit unknown. Like grappling hooks for mountain climbers, bridging sets an anchor in levels not attained yet and pulls the developmental process toward constructing these levels. (3) During bridging, people function simultaneously on two different levels of knowledge. On the one hand, they work directly on the task at hand, often functioning at a low level, especially in tasks that are novel for them. On the other, they work at a higher level where they construct a bridging shell, albeit still empty of content knowledge. They use the higherlevel shell to guide their knowledge construction by gradually filling in the shell's unknown components.

We demonstrate the use of bridging with skill theory's (Fischer, 1980) formulation. To keep the presentation easily understandable, we use the skill level of mappings of actions for all examples. A skill of mapping interrelates two actions or factors, such as cause-and-effect. For example, a cause (Jack falls down) is related to its result (water in pail spills)[1]:

$$\left[\underset{\textbf{FALLS}}{\textbf{JACK}} \text{———} \underset{\textbf{SPILLS}}{\textbf{WATER}} \right] \quad (1)$$

Bridging occurs when, for example, a child gives some indication of the existence of a cause before constructing the skill for understanding the causality. There is only a glimpse of causality: neither the cause nor the effect is explicitly mentioned. Instead, a partial and ambiguous statement gives a hint for a budding realization that causality may exist. The statement creates a shell,

$$\left[(\mathbf{X_a}) \text{———} (\mathbf{Y_b}) \right] \quad (2)$$

with unknown variables. $\boldsymbol{X_a}$, $\boldsymbol{Y_b}$ are unknown variables. The variables are implied (not stated explicitly), which is represented by their enclosure in parentheses. Bridging shells can be created in a few ways, corresponding to several bridging forms.

Forms of bridging. Bridging shells can occur in different ways, creating several bridging forms, each of which can be used as self-scaffolding tools. For instance, in a bridging term, people create a shell by stating a specific term that implies a causality between two unknown and implied variables:

$$\left[(\mathbf{X}_{\mathbf{a}}) \overset{\text{Term}}{\text{———}} (\mathbf{Y}_{\mathbf{b}}) \right] \tag{3}$$

In such a case, the primary indication for understanding the causality is the use of the specific term. There is no other reference to cause and the effect (Granott, 1993a). In *bridging* term, then, a single word creates a shell that implies a higher target level with empty slots.

Other ways that people create bridging include using a specific sentence format, asking a question, declaring an intention, or recasting a statement and reiterating it differently (Granott, 1993a). All the bridging forms are created similarly, by outlining implied shells of more advanced knowledge than previously specified, while leaving out the shells' unknown contents. They all operate by guiding the activity to gradual construction of the missing knowledge. Specifying the different forms of bridging can help to identify the spontaneous use of this mechanism in real-time activities.

In a *bridging format,* the syntax or format of a statement creates a shell with missing content. A person sets up a shell by making an incomplete statement, as in an "if... then" statement that omits the content of the "if" or the "then" part. Typically, a pause or a gesture marks the omitted content. In discourse, people often make partial statements, leaving a sentence incomplete and continuing to make another. They may not finish statements for various reasons, such as skipping obvious content instead of repeating it unnecessarily. Unlike such cases, what distinguishes bridging format is that people leave out information that is still unknown[2]. By outlining a format that indicates missing knowledge, they form a shell that creates access to this knowledge, guides their exploration, and gradually helps them to construct the target knowledge.

In other bridging forms, similar shells are created by other means. In *bridging question,* people ask a question that outlines a shell with unknown components as a target for future development. In *bridging intention,* they state what they intend to do when the way to achieve it is still unknown. In *bridging recast,* they create a shell by a lower-level formulation followed by a higher-level reformulation, Before explaining in more details how bridging occurs, we demonstrate it by example from real-time activity in microdevelopment.

How Bridging Operates in Real-time Activities

The following episode, which demonstrates the use of bridging, is taken from a study on microdevelopmental co-construction of scientific knowledge (Granott, 1993a, 1998a, this volume). Eight graduate students were asked to discover and understand the operation of unfamiliar Lego robots called "wuggles". The wuggles reacted to light, sound, and touch by changing their movement patterns. The participants explored the wuggles in a room especially designed to include diverse stimuli that affected the robots' movement in different ways. The collaborative activity continued for four one-hour sessions. Within the general task, the participants defined their own goals, problems, and strategies.

The participants constructed bridging shells spontaneously in their attempts to bootstrap their understanding of how the wuggles functioned. For example, Kevin and Marvin explored a wuggle that responded to changes in light. When they first encountered the robot, Kevin and Marvin did not know what affected it or even that it had specific sensors. They tried to understand how the wuggle operated by playing with it, placing their hands around it in different ways, and observing its movement. After a brief exploration, they showed their first bridging - a vague, tentative allusion to undefined cause-and-effect. As Marvin was putting his hand around the robot, Kevin commented:

"Looks like we got a reaction there."

The term "reaction" implied cause and effect, action and response (re-action). Yet Kevin specified neither the cause nor the effect. At this time, it was unclear what was causing the robot's changing movement and how the robot moved differently, because Kevin and Marvin had not identified yet any patterns in its complex movement. Kevin used a bridging term ("reaction"), which merely alluded to an unknown causality:

$$\left[(\mathbf{X}_\mathbf{a}) \overset{\text{Reaction}}{\text{———}} (\mathbf{Y}_\mathbf{b}) \right] \tag{4}$$

The only explicit component in the shell is the term "reaction", which implies a causal relation between two unknowns – action X_a and response Y_b.

Skill (4) demonstrates how bridging operates in real-time activity in context. (1) People spontaneously make a statement that implies a target-level shell of more advanced knowledge than currently specified. (2) Important content of the shell is still missing. In the example, the first condition is fulfilled because the term "reaction" implied a shell of some causal relation, when Kevin and Marvin have not specified any causal relation before. The shell was still empty of content: the causal relation and its components were still unknown. Even though the shell was merely implied, the statement indicated progress and assisted the construction of the missing knowledge (Granott, 1993a).

As the example demonstrates, bridging in development occurs much like the construction of bridges over highways. In actual bridges, pillars are frst erected. These pillars do not support anything yet, because the horizontal part of the bridge, on which the road will pass, is still missing. Yet the "empty" pillars mark the future road. Later, horizontal structures are built over the pillars, bridging from one place to another. Similarly, in developmental bridging, people first set up an empty structure, which, like the pillars, sketches the way for building new knowledge. Then, people fill the empty structure with relevant content, thereby reaching the target knowledge. In the example, bridging merely outlined an undefined structure, just like pillars of future bridges. The content of Kevin's statement – the specific cause and effect – was still missing, like the horizontal beams between the pillars. By outlining a target level, the shell guides toward further development, as we demonstrate later.

Bridging as an Attractor for Future Development. Although the bridging shell does not carry content, it is functional, serving as a goal for learning. It is fundamentally different from a statement in which this knowledge is missing without acknowledging its existence. The vacant structure traces a goal for future development and, like an attractor, pulls the process toward it. By directing new experiences toward gradual construction of the shell's target level, the bridging attractor acts as a catalyst of self-organization, leading to selfguided constriction of higher-level structures. These structures are more complex and explicit than those that gave rise to the attractor.

In the "reaction" episode, merely outlining a missing causality created a target level that directed the participants' observations and actions. After the bridging statement, Kevin and Marvin focused on discovering the missing causality, as evidenced in their activity and conversation. By playing with the wuggle and observing its movement, they tried to identify its reactions to their actions and its pattern of movement. The shell guided them toward making more elaborate distinctions about their own actions and the robot's movement.

In their progress toward constructing the knowledge outlined by the shell (4), Kevin and Marvin created a series of bridging statements that gradually filled in the missing components in (4). For instance, they created bridging with the unfinished statement "You're getting a different reaction when you're putting your hand on it instead of when you put your hand ... ." Although this shell included some information, part of the action was not specified (put your hand where?) and so was the robot's movement (what different reaction?) They went on, continually steering their exploration toward the shell's target level, Kevin and Marvin gradually progressed. Their observations contributed to increasing specification of the wuggle's movement: "Sometimes it goes one way..." and of relevant environmental conditions: "Look, we've got light problems too". They wondered if light and shadow had any effect: "Light and shadows [do] anything?" but also asked about sound: "Uh, actually, does it have anything [to do] in relation to the sound the taperecorder is playing?" This series of statements increasingly specified components of possible cause and effect relations pertaining to the wuggle's movement.

In dynamic systems terms, bridging operates as an attractor -- a relatively stable state to which the system gravitates, a state that attracts the system to it. In the process of knowledge construction, bridging shells operate as attractors, pulling skills toward higher developmental levels. An attractor-shell functions like a grappling hook for mountain climbers: it pulls knowledge and understanding up, toward the target level.

Bridging takes place not only from existing knowledge toward the new, but also from the shell's target level toward the current skill, in a top-down pull. The target level serves as a magnet, attracting the process of knowledge construction toward a more complex skill. The top-down pull in developing toward the attractor is created because bridging creates a lens for observing and interpreting events. Even when a bridging shell is completely empty, it establishes a new perspective and affects people's ways of thinking. By processing information from the perspective set by the shell, a person considers different parts of the situation, works them through within that perspective, and gradually constructs new, higherlevel knowledge that fills the shell. In this way, the pull of bridging as an attractor creates "self-fulfilling" structures for future knowledge.

The initial shell (4) created such a lens for Kevin and Marvin. It directed their actions, gave focus to their observations, and guided their processing of new experiences. Through activity directed toward the higher-level attractor, Kevin and Marvin later formulated their first causal mapping when they said: "When it comes over here and as soon as it gets underneath part of the shadow there, it starts changing its behavior." They stated a simple causal relation between the robot's being under shadow and its changed behavior, which finally gave shell (4) full content.

[SHADOW —— IT (WUGGLE)] (5)
(ON WUGGLE) CHANGE(S) BEHAVIOR

Bridging specifies the way an attractor starts operating when its manifestation just emerges. First, bridging gives an initial indication of missing knowledge in an empty shell. Then, it guides the subsequent activity, which becomes focused on the shell's target level, and increasingly constructs component of the shell. Gradually, the activity fills the shell with content, stimulates hypotheses, and eventually leads to constructing the target level and reaching the attractor. Along the way, unfit shells can also be revised or abandoned, based on results of the activities, so that the target structure changes.

<u>What Bridging and What It Is Not: Bridging versus Hypotheses</u>. The initial bridging statement is not a hypothesis, because it is vague and undefined, only outlining an empty structure. But it is an attractor, fully functioning to guide the activity toward developmental progress. When an undefined shell becomes increasingly specified and more defined, it turns into a hypothesis.

An example from Parziale's study (1997, this volume) demonstrates the difference between bridging and hypothesis testing. Parziale studied the way 5^{th} and 7^{th} graders constructed marshmallow-and-toothpick bridges. When Mary and Beth, two 5^{th} graders, first faced their task, they did not know how to begin their construction. Mary asked: "How are we going to do this?" Clearly, Mary's question was not a hypothesis. Yet as a bridging question, it directed further activity. Mary's statement created a shell with mussing content related to her and Beth's action (Xa) and an unspecified component related to the bridge structure ("this"):

$$\left[(\mathbf{X_a}) \xrightarrow{\text{how?}} \mathbf{THIS_{(b)}} \right] \tag{6}$$

A statement made during the activity of two other 5th graders demonstrates even more explicitly that bridging appears before any hypothesis. Josh and Will, who had doubled the toothpicks between every two marshmallows, were running out of toothpicks. Observing their bridge, which was sagging despite the doubled toothpick connections, Will said: "Hey, Josh. Let's not double. Doubling doesn't work as well as if we... Actually, I don't know about that."

Will expressed his dissatisfaction with the strategy of doubling and, using bridging format, compared it to a better, yet unknown, strategy. Will explicitly said he did not know what an alternative strategy might be. Because he did not have a hypothesis yet, he left the alternative strategy unspecified in the incomplete sentence.

The pre-hypothesis function of bridging cannot be attributed to age: it appeared also in adults' activities (Granott, 1993a). For example, in the wuggle study, Ann and Donald were observing a robot that was moving on the floor when the robot suddenly stopped. Bewildered, Ann asked: "What caused it to stop?" At this time, Ann did not have any hypothesis. Yet her bridging question directed the continued activity in search of an answer.

An initial bridging often triggers a series of bridging statements that become increasingly specified. As the activity proceeded, participants in our studies created more advanced bridging shells that indeed served as hypotheses. For example, Mary's question provided a scaffold for initiating a plan. Beth answered: "Well, to make it go across we could do something like this." While talking, Beth placed toothpicks next to each other in the form of a letter H. Her answer started filling in the missing components in (6):

[**DO SOMETHING** ——— **IT (BRIDGE)**] (7)
LIKE THIS (H) **GO(ES) ACROSS**

By placing toothpicks in an "H" shape, Beth traced a proposed structural unit for the bridge construction. Her answer and action provided a hypothesis, suggesting that by using H units, they could construct the desired bridge.

Similarly, in the other bridge-building dyad, Will's bridging shell, albeit empty, directed the dyad's activity toward identifying an alternative strategy. The dyad continued to experiment with doubling the toothpicks. They started filling the missing components and then explicitly suggested a different strategy when Josh said "Got to make Xs on the base". This statement specified a hypothesis for their continued construction.

Ann and Donald's activity showed a similar pattern with the wuggle. The shell created a *focus for* their observations, which soon led to discovering the missing causality. When Donald started talking loudly, the robot moved and Ann exclaimed: "Voice start. Voice!" stating a causal mapping between sound (voice) and the wuggle's movement. At this time, the statement "Voice start" became a hypothesis that Ann started testing by clapping and snapping fingers.

These examples demonstrate the way initial bridging differs from hypothesis testing. While a hypothesis indicates an assumed structure of knowledge, a bridging shell marks the lack thereof. It does not state a possible structure to be tested, but outlines a vacant structure. Bridging puts a place-holder for missing knowledge. It is used when there is not enough knowledge to formulate a hypothesis. However, bridging guides the activity and prepares the way for formulating a hypothesis later. The missing shell directs the continued activity toward filling the missing knowledge. As more knowledge is constructed and components of the shell are increasingly specified, a more advanced bridging shell can serve as a hypothesis.

Bridging as a Scaffold. An empty bridging shell operates as a scaffold for future knowledge. It gives structure to knowledge that is still unknown, outlines a missing relation between its components, and gives a goal for the following activity. Stating or acting out a shell that outlines missing knowledge is similar to drafting an initial outline before writing a document. Like a bridging shell, the document's outline is still missing its content, which is not spelled out yet. However, when an initial outline is tentatively sketched, it guides the construction of the actual document.

Bridging is a self-scaffolding mechanism that bootstraps one's own knowledge. It is used by individuals or in collaborative co-construction when people work closely together on a task. By sharing with each other their thoughts, questions, and observations, collaborating partners state bridging shells that scaffold their continuing activity. Within these scaffolds, future knowledge and skills can develop.

For instance, some time after defining shell (4), Marvin and Kevin watched their wuggle as it moved on a floor, passed under a bridge, continued to the other side of the bridge, and then stopped close to a box. Marvin said: *"Let's see if I can make it come back."* Marvin expressed an intention to make the robot come back, but did not specify how he would do it. The cause for the wuggle's movement have been the focus of Kevin and Marvin's exploration since their initial shell (4). Now, Marvin's statement created the following new shell:

[**MAKE** (**a**) —Let's see if?— **IT (WUGGLE)** **COME(S) BACK**] (8)

In the shell (8), the action was not specified. Still, the statement created a scaffold for constructing the missing knowledge by indicating a target for future activity. Marvin proceeded to play with the lamp, changed its direction in several ways, and indeed made the robot come back.

As a scaffold, bridging can explain construction that is otherwise puzzling. An example from engineering scaffolding can illustrate this point[3]. The Roman or Gothic arches are logically impossible to construct: the central closing stone is needed for keeping the lateral supporting stones in place, and the lateral supporting stones are needed to keep the closing stone in place. Scaffolding solves this "logical impossibility." By constructing a wooden support for the arch, constructors can assemble the stones on the wooden support. When the stone structure is completed, the wooden support can be removed and the stone structure will support itself. Bridging-shell scaffolds assist development similarly. *It seems logically impossible to construct missing knowledge, because one does not know yet what to construct. By outlining the missing knowledge, the shell creates a scaffold that makes the construction possible*.

Bridging as a Transition Mechanism. As a transition mechanism, bridging operates in several ways. First, it operates through a series of increasingly specified statements and shells that gradually fill an initial shell. The previous examples demonstrate increasing specification of the initial shell (4) through a series of statements and shells, like (8), until its fulfillment into fully specified structures, as in (5). Second, bridging involves a series of shifting target shells at a given level to generalize a skill. People create a succession of shifting shells to deal with different aspects of a task at their current level, as did Kevin and Marvin when exploring the effects of sound as well as light. Third, development consists of successive shells of more complex skills, shifting to increasingly higher levels.

While initial bridging bootstraps skill development from empty shells, more advanced bridging facilitates the emergence of major qualitative reorganizations from partially filled shells. For example, when Josh and Will were building their bridge, they used bridging to progress from a two-dimensional to a stronger three-dimensional structure. They began with a two-dimensional hexagon units with toothpick “spokes” leading to a centered marshmallow. Josh used a bridging question by asking if they should continue adding units in the same plane or build upwards, adding a third dimension: "Are we going to make a higher level, or are we going to just keep on building like that?" While speaking, Josh represented the shell visually by holding a toothpick vertically over a unit that was lying flat on the table. His question shell and action outlined two optional strategies-flat or threedimensional structure-when the way to execute the strategies remained unknown. Later, this shell led Josh and Will's activity to a major advance. They inserted a toothpick in a way that created a third dimension and began building vertically off the flat structure. Testing their bridge provided them with feedback about the effect of their strategies and helped them understand the missing variables in the shell (Parziale, this volume).

An important kind of shell for such major reorganizations is a bridging recast, which reformulates or recasts the structure of understanding into a higher-level shell. For instance, when Ann and Donald were exploring the robot's response to sound, Donald said: "It goes not from the talking but from the difference in the loudness." Later, he reformulated the idea of loudness-difference from the perspective of what the wuggle sensed: "See, I think that it must have to sense that there's loudness difference". The recast bridged the way from description of the movement to explanation, knowledge that was only implicit in the previous statement.

Another way in which bridging operates as a transition mechanism is by revising and changing content knowledge. Again, the process is similar to the transition from an outline to a written document. When writing the outlined document, an author often makes substantial changes. In bridging, people make similar changes when filling a tentative outline set by a shell. The outline can either be supported by the continuing activity and filled with content or discarded when further activity leads to knowledge incompatible with the shell. In both capacities, bridging leads to further progress.

For example, having made the hypothesis that their robot responded to sound, Ann put forth a new shell, saying: "I think it's directional." The term "directional" indicated that direction was important somehow, though its effect on the robot's movement was undefined because it was still unknown. Ann went on to explore the effect of direction by clapping at one side of the robot and then at the other. Following some further exploration, she and Donald concluded that the sound's direction had no effect on the robot's movement: "So, you don't think it's where the noise comes from." The bridging shell set forth by the term "directional" created a target level that led the activity and was then invalidated. Developing understanding depends as much on such instances of discarding wrong shells as it does on building shells that bridge to correct knowledge and skills.

The Prevalence of Bridging: Discussion and Implications

The developmental mechanism of bridging gives an answer to a question that has puzzled researchers for centuries: how does development occur? Specifically, how do higher-level structures of knowledge in action and speech develop out of lower-level structures? We describe a developmental transition mechanism called bridging that gives an answer to this question. We suggest that the answer can be found in all aspects of life. People routinely formulate undefined bridging shells that use the structure of higher-level skills and knowledge but leave components empty or vague. They then use those shells to guide their learning and problem solving and gradually fill the missing components. As shells are transformed into explicit skills, people continue to use bridging to achieve still higher levels. They create a series of shifting shells, scaffolding their own learning and development to increasingly higher levels of knowledge.

During bridging, people routinely operate at multiple levels simultaneously. They function at established levels of knowledge, where they use explicit, well-defined skills. Yet they also function at higher levels when constructing bridging shells as targets for future knowledge. By working toward filling the shells with content, they bridge the gap between the two levels. Through bridging across levels, people continue to improve their skills and understanding.

Bridging clarifies how people use existing structures to construct new knowledge. They state terms that imply higher-level shells. They use sentence formats that include empty components. They ask questions for which they have no answers. They state intentions to perform an act when the way to do it is still unknown. They recast an idea at a higher, still unknown level. Through these forms of bridging, people create goals for their learning and development and direct themselves to construct new knowledge.

The function of bridging for guiding development explains how people grope toward new knowledge in ways that seem to reflect a goal-oriented process. The phenomenon is paradoxical, since this goal-oriented process is guided by an unknown goal: the target shell represents knowledge that is still missing. A few researchers have noted this puzzle previously. For example, Siegler & Jenkins (1989) conclude that children do not proceed in a haphazard, trial-and-error manner when generating new strategies for solving problems. Siegler suggests that "one possibility is that even before discovering new strategies, children understand the goals that legitimate strategies in the domain must satisfy" (Siegler, 1994, p. 4). Bridging may explain this pattern of development, because when building shells people use vague, tentative, and undefined notions of still-missing knowledge to create goals for their own learning and development.

In our studies too, participants did not make random attempts to understand a robot or build a marshmallow-toothpicks bridge. Instead, their actions and discourse were directed by goals set by their bridging shells. Bridging sheds light on the puzzling attribute of development toward the unknown since in bridging even missing knowledge can be used to set targets to guide future development.

We suggest that bridging operates at all ages, not only at the ages that we studied. Bridging is similar to Piaget's (1936/1952) description of groping behavior in infancy. When infants encounter a new situation, they try out different actions to grope toward a target of effective actions. They produce what Piaget, following Baldwin (1894), called circular reactions-repetitions of similar actions in groping toward a goal. According to Piaget, groping can occur in two ways, corresponding to two extremes of the same phenomenon. Some groping is non-systematic, occurring through fortuitous discovery, chance occurrence, and trial and error. Other groping is systematic, occurring through directed activity that is based on some comprehension, like the use of bridging shells. Piaget argued that infant groping is mostly systematic and directed, albeit at times in a vague and general way. According to Piaget (and Claparede, 1931), groping in infants starts as awareness of a possible relation between actions, such as means-end-like the bridging shell (4) described above. Then, groping leads to repetition of similar but varied actions. We suggest that bridging explains this phenomenon: infants use bridging to guide their exploration and pave the way to discovering new relations. Through circular reactions, they fill components and interrelations that were missing in the shell and gradually develop their skills and knowledge. In this way, the shells operate as attractors in dynamic systems, guiding actions and observations for infants, children, and adults. Through a series of shifting, increasingly defined bridging shells, a person constructs new knowledge at levels higher than she or he has constructed in that domain.

Once we discovered bridging, we could see its prevalence in interactive activities, individual knowledge construction, and discovery. Parents, teachers, and employers use bridging techniques intentionally. Bridging appears in diverse contexts, like home, school, or the workplace, and in various activities, including therapy, counseling, and planning.

Parents offer children bridging shells in various ways. In language, for example, they use bridging terms by uttering partial words and letting the children continue them. They use bridging formats by starting a sentence and waiting for the children to complete it. They use bridging questions by asking a question and guiding the children to answer it. They use bridging intentions and prompt the children to participate in translating the intention into action. They use bridging recasts by reformulating children's utterances for correcting them or to better fit the task demands. Parents use bridging techniques when they collaborate on a task with children, performing part of the task and leaving the rest, partly defined, for the children to do.

At school as well, teachers utilize bridging as learning tools. Using bridging terms, teachers introduce key words that guide the children's activity and discussion. Using bridging questions, they formulate questions that lead students to make statements they have not made before. Using bridging formats, they begin a statement or an activity and ask students to complete it. Using bridging intentions, they indicate intentions that operate as goals for the students' activity. Using bridging recasts, they reformulate students' answers, providing more advanced knowledge. Teachers make comments that suggest problems or hint at solutions in ways that require students to formulate the problems or find the solutions. Through such bridging shells, they lead students to construct new knowledge.

In the workplace, formulation of targets as operational goals is a well-practiced technique. Salespersons have quotas, manufacturing units have production targets, and managers have pre-formulated goals. When these goals are set, the ways to reach them are often unknown. Setting the goals defines targets that guide further growth, just as bridging does in learning and development.

Across settings, especially in middle childhood and beyond, people often ask themselves questions or set for themselves incomplete tasks. These questions and tasks, whether set explicitly or implicitly, serve as bridging for knowledge construction. People raise questions about specific issues and later look for answers to their questions. Sometimes the questions lead to a prolonged process of discovering the answers. At other times, an answer "presents itself": the well-prepared mind, which asked the question, picks the answer from the stream of events.

Bridging appears to be prevalent. Yet the role of partial, vague, and undefined knowledge has often been denied. For example, Vygotsky (1962, p. 163) claimed that a "need is not a sufficient explanation for any developmental change." Yet, as we have demonstrated, a need can guide learning and development through partial, vague definitions of target levels. To trigger bridging, needs must be defined only enough for a person to create an empty shell that guides further activity. Shells can serve as attractors in the dynamics of activity, pulling knowledge toward the goal indicated by the need. A need expressed in a vague statement may be a sufficient trigger for developmental change.

In this chapter we have pointed out the existence of bridging and defined how it occurs. Further extensive research is essential for analyzing bridging and constructing indepth understanding of its contribution to transitions in development and learning. The description of bridging and the analysis of the way it works, presented in this chapter, may provide a shell for further understanding how bridging functions to create learning and development.

References

Baldwin, J. M. (1894). Men development in the child and the race: Methods and processes. New York: MacMillan

Bowerman, M. (1989). Learning a semantic system: What role do cognitive predispositions play? In M. Rice & R. Schiefelbusch (Eds.), The teachability of language (chap. 4). Baltimore: Paul H. Brookes.

Bronfenbrenner, U. (1993). The ecology of cognitive development: Research models and fugitive findings. In R. Wozniak & K. W. Fischer (Eds), Development in context: Acting and thinking in specific environments (pp. 3-44). Hillsdale, NJ: Erlbaum.

Brown, R. (1973). A first language: The early stages. Cambridge, MA: Harvard University Press.

Case, R. (1991). A developmental approach to the design of remedial instruction. In A. McKeough & J. Lupert (Eds.), Toward the practice of theory-based instruction (pp. 117-147). Hillsdale, NJ: Erlbaum.

Case, R., & McKeough, A. (1990). Schooling and the development of central conceptual structures: An example from the domain of children's narrative. International Journal of, Educational Psychology, 8, 835-855.

Case, R, Okamoto, Y., Griffin, S., McKeough, A., Bleiker, C., Henderson, B., & Stephenson, K. M. (1996). The role of central conceptual structures in the development of children's thought. Monographs of the Society for Resarch in Child Development, Serial No. 246, Vol. 61(1-2).

______Chomsky, N. (1975). Reflections on language. New York: Pantheon.

Chomsky, N. (1980). On cognitive structures and their development: A reply to Piaget. In M. Piatelli-Palmarini (Ed.), Language and learning: The debate between Jean Piaget and Noam Chomsky (pp. 35-52). Cambridge, MA: Harvard University Press.

Claparède, E. (1931). L'éducation fonctionnelle. Paris et Neuchatel: Delachaux & Niestlé.

Cole, M. (1988). Cross-cultural research in the sociohistorical tradition. Human Development, 31,137-157.

Damasio, A. R, & Damasio, H. (1992). Brain and language. Scientific American, 267(3), 89-95.

Dromi, E. (1996). Early lexical development (First published in 1987). San Diego: Singular Publishing.

Duncker, K. (1945). On problem solving. Psychological Monographs, 58, (Whole no. 270).

Elman, J. L., Bates, E. A., Johnson, M. H., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). Rethinking innateness: A connectionist perspective on development. Cambridge, MA: The MIT Press.

Fischer, K. W. (1980). A theory of cognitive development: The control and construction of hierarchies of skills. Psychological Review, 37, 477-531.

Fischer, K., W., & Ayoub, C. (1994). Affective splitting and dissociation in normal and maltreated children: Developmental pathways for self in relationships. In D. Cicchetti & S. L. Toth (Eds.), Rochester Symposium on dysfunctions of the self (pp. 149-222). Rochester, NY: University of Rochester Press.

Fischer, K. W., & Bidell, T. R. (1998). Dynamic development of psychological structures in action and thought. In R. M. Lerner (Ed.), Handbook of child psychology (pp. 467-561). NY: Wiley.

Fischer, K. W., Bullock, D. H., Rotenberg, E. J., & Raya, P. (1993). The dynamics of competence: How context contributes directly to skill. In R H. Wozniak & K. W. Fischer (Eds.), Development in context: Acting and thinking in specific environments. Hillsdale, NJ: Erlbaum.

Fischer, K. W., & Granott, N. (1995). Beyond one-dimensional change: Multiple, concurrent, socially distributed processes in learning and development. Human Development, 38, 302-314.

Fischer, K. W., & Rose, S. P. (1994). Dynamic development of coordination of components in brain and behavior. A framework for theory and research. In G. Dawson & K. W. Fischer (Eds.), Human behavior and the developing brain (pp. 3-66). New York: Guilford.

Fischer, K. W. & Yan, Z. (this volume). Darwin's construction of the theory of evolution: Microdevelopment of explanations of species' variation and change.

Fodor, J. A. (1975). The language of thought. Cambridge, MA: Harvard University Press.

Gelman, R., Romo, L., & Francis, W. (this volume). Notebooks as windows on learning: The case of a science-into-ESL program.

Gesell, A. (1940). The first five years of life. New York: Harper & Row.

Goldin-Meadow, S., & Alibali, M. W. (this volume). Looking at the hands through time: A microgenetic perspective on learning and instruction.

Goldin-Meadow, S., Nusbaum, H., Garber, P., & Church, R. B. (1993). Transitions in learning: Evidence for simultaneously activated rules. Journal of Experimental Psychology: Human Perception and Performance, 19, 92-107.

Gottlieb, G. (1991). Experiential canalization of behavioral development: Theory. Developmental Psychology, 27(1), 4-13.

Granott, N. (1992). Microdevelopmental puzzle and the mechanism of cognitive growth: Alternative pathways, parallel access, and co-existing structures. Paper presented at the 22nd Annual Symposium of the Jean Piaget Society, Montreal, Canada.

Granott, N. (1993a). Microdevelopment of co-construction of knowledge during problem-solving: Puzzled minds, weird creatures, and wuggles (Doctoral dissertation, Massachusetts Institute of Technology, Cambridge, MA) [on line]. Available: http://theses.mit.edu:80/Dienst/UI/2.0/Composite/0018.mit.theses/1993-170/1?nsections=19

Granott, N. (1993b). Patterns of interaction in the co-construction of knowledge: Separate minds, joint effort, and weird creatures. in R. Wozniak & K. W. Fischer (Eds.), Development in context: Acting and thinking in specific environments (pp. 183-207). Hillsdale, NJ: Erlbaum.

Granott, N. (1994). On the mechanism of cognitive change: Transition mechanism in microdevelopment and the "Zone of Current Development". Paper presented at the Annual Symposium of the Jean Piaget Society, Chicago, IL.

Granott, N. (1998a). We learn, therefore we develop: Learning versus development or developing learning? In C. Smith & T. Pourchot (Eds.), Adult learning and development: Perspectives from educational Psychology (pp. 15-34). Mahwah, NJ: Erlbaum.

Granott, N. (1998b). Unit of analysis in transit: From the individual's knowledge to the ensemble process. Mind. Culture, and Activity: An International Journal, 1(1), 42-66.

Granott, N., & Parziale, J. (1996, June). Bridges to and from the unknown: The developmental mechanism of bridging. Paper presented at the 26th Annual Symposium of the Jean Piaget Society. Philadelphia, PA.

Granott, N. (this volume).

Grossberg, S. (1987). The adaptive brain (2 vols.). Amsterdam: Elsevier/North Holland.

Inhelder, B., & Piaget, J. (1958). The growth of logical thinking from childhood to adolescence (A. Parsons & S. Seagrim, Trans.). New York: Basic Books. (Originally published, 1955).

Klahr, D. (1992). Information-processing approaches to cognitive development. In M. H. Bornstein & M. E. Lamb (Eds.), Developmental psychology: An advanced textbook (pp. 273-335). Hillsdale, NJ: Erlbaum.

Klahr, D., Faye, A. L., & Dunbar, K. (1993). "Heuristics for scientific experimentation: A developmental study." Cognitive Psychology, 25,111-146.

Krech, D. (1932). The genesis of "hypotheses" in rats. University of California Publications in Psychology, 6, 45-64.

Kuhn, D. (this volume). A multi-component system that constructs knowledge: Insights from microgenetic study.

Kuhn, D., Garcia-Mila, M., Zohar, A., & Andersen, C. (1995). Strategies of knowledge acquisition. Monographs of the Society for Research in Chid Development, Serial No. 245, 60(4).

Lee, K., & Karmiloff-Smith, A. (this volume). Macro- and microdevelopmental research: Assumptions, research strategies, constraints, and utilities.

Leontiev, A. N. (1981). The problem of activity in psychology. In J. V. Wertsch (Ed.), The concept of activity in Soviet Psvchology (pp. 37-71). Armonk, NY: Sharpe.

Lerner, R. M. (1991). Changing organism-context relations as the basic process of development: A developmental contextual perspective. Developmental Psychology. 27(1), 27-32.

Lewis, M. (this volume). Emotion and emergence over time scales of development: The self-organization of individual styles.

Marcel, A. J. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. Cognitive Psychology, 15, 197-237.

MacWhinney, B., & Leinbach, J. (1991). Imprlementations are not conceptualizations: Revising the verb learning model. Cognition, 40, 121-157.

Mead, G. H. (1934). Mind. self, and society. Chicago: University of Chicago Press.

Miller, P. H., & Aloise-Young, P. A., (1995). Preschoolers' strategic behavior and performance on a same-different task. Journal of Experimental Child Psychology, 60 (2), 284-303.

Miller, P. H. and Coyle, T. R (1999), Developmental change: Lessons from microgenesis. Conceptual deelopment: Piaget's legacy. E. K. Scholnick, K. Nelson, S. A. Gelman and P. H. Miller. Mahway, NJ: Erlbaum.

Schauble, L. (1990). Belief revision in children: The role of prior knowledge and strategies for generating evidence. Journal of Experimental Child Psychology, 49, 31-57.

Schauble, L. (1996). The development of scientific reasoning in knowledge-rich contexts. Developmental Psychology, 32(1),102-119.

Siegler, R. S. (1994). Cognitive variability: A key to understanding cognitive development. Current Directions in Psychological Science 3(1), 1-5.

Siegler, R. S. (1996). Emerging minds: The process of change in children's thinking. New York: Oxford University Press.

Siegler, R. S. (this volume). Microgenetic studies of self-explanation.

Siegler, R. S., & Crowley, K. (1991). The microgenetic method: A direct means for studying cognitive development American Psychologist, 46, 606-620.

Siegler, R. S., & Jenkins, E. (1989). How children discover new strategies. Hillsdale, NJ: Erlbaum.

Simon, T. J., & Halford, G. S. (Eds.). (1995). Developing cognitive competence: New approaches to process modeling. Hillsdale, NJ: Erlbaum.

Smith, L. B., & Thelen, E. (Eds.). (1993). A dynamic systems approach to development: Appliations. Cambridge, MA: The MIT Press.

Thelen, E., & Corbetta, D. (this volume). Microdevelopment and dynamic systems: Applications to infant motor development.

Thelen, E., & Smith, L. B. (1994). A dynamics sstems approach to the development of cognition and action. Cambridge, MA: The MIT Press.

Tolman, E. C. (1948). Cognitive maps in rats and men. Psychological Review, 51, 189-208.

van Geert, P. (1991). A dynamic systems model of cognitive and language growth. Psychological Review, 98, 3-53.

van Geert, P. (1994). Dynamic systems of development: Change between complexity and chaos. New York: Harvester Wheatsheaf.

van Geert, P. (1998a). We almost had a great future behind us: The contribution of non-linear dynamics to developmental-science-in-the-making. Developmental Science 1(l), 143-159.

van Geert, P. (1998b). A dynamic systems model of basic developmental mechanisms: Piaget, Vygotsky, and beyond. Psychological Review, 105(4), 634-677.

van Geert, P. (this volume). Developmental dynamics, intentional action, and fuzzy sets.

Vygotsky, L. (1962). Thought and language. The MIT Press.

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Cambridge, MA: Harvard University Press.

Werner, H. (1948). Comparative psychology of mental development. New York: International Universities Press.

Werner, H. (1957). The concept of development from a comparative and organismic point of view. In D. B. Harris (Ed.), The concept of deelopment: An issue in the study of human behavior. Minneapolis: University of Minnesota Press.

Wertsch, J. V. (1985). Vygotsky and the social formation of mind. Cambridge, MA: Harvard University Press.

[1] Structure (1) uses skill theory notation. Square brackets indicate a skill and a line denotes a mapping between the two parts of the skill.

[2] In studies of microdevelopment, it is possible to encapsulate and document the process of learning a specific issue, especially when it is related to a new context. Microgenetic data can show, therefore, when specific information is still unknown and when it is acquired.

[3] We thank Paul van Geert for this example.