Beyond One-Dimensional Change: Parallel, Concurrent, Socially Distributed Processes in Learning and Development

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Abstract
Development and learning involve similar changes in the organization of behavior, within different time frames. A potentially powerful way to relate learning and development is through the study of microdevelopment, in which short-term changes are analyzed as developmental functions. Research on microdevelopment has been stymied, however, by assumptions that have restricted analysis to nonecological, one-dimensional concepts. Traditional paradigms assume erroneously that a solitary individual develops along a single linear pathway. Moving beyond these one-dimensional concepts opens up microdevelopment as an exciting and fundamental arena for research. Learning and problem solving are distributed socially among members of small ensembles. Communication among members externalizes much of the process of microdevelopment, providing extensive information for researchers. Growth occurs along multiple concurrent strands, forming a developmental web; each strand is in turn composed of multiple concurrent threads. In different strands and threads, individuals and ensembles function at widely different developmental levels, and they grow in diverse nonlinear dynamic shapes. An example of problem solving involving an unfamiliar device illustrates how adding these complexities in fact simplifies microdevelopment research and theory.

The perennial debates about relations between learning and development have generally led to the unproductive conclusion that one or the other is primary. Either development is nothing but accumulations of many things that have been learned [Klahr and Wallace, 1976; Miller and Dollard, 1941; Skinner, 1969], or learning is nothing but performance of circus-like tricks, in contrast to the true changes that constitute development [Kohlberg, 1969; Piaget, 1947/1950]. The real outcome of arguments like these is always the continuation of debate, with no resolution possible.
To move beyond such fruitless debate, researchers need to analyze learning and development together. If learning is a class of short-term changes leading to new knowledge and skill, and development is a class of long-term changes leading to new knowledge and skill, researchers should be able to use a framework for change in knowledge and skill to analyze both learning and development, as well as related types of change such as problem solving and the growth of expertise. Building such a framework, however, requires changing the way that research is done – specifically, moving beyond a set of implicit assumptions that have restricted analysis to unrealistic, one-dimensional models of development.

Various investigators have attempted to build a framework to combine learning and development by studying microdevelopment – the gradual acquisition or construction of a solution to a problem over a relatively short time period, ranging from minutes or hours to days, weeks, or even months. Traditional models of microdevelopment emphasize processes such as differentiation, integration, association, and movement from disconnected parts to connected wholes [Duncker, 1935/1945; Fischer, 1980a,b; Inhelder et al., 1974; Werner, 1948, 1957].

Recently, there has been a modest surge in microdevelopmental research, with calls for intensive investigation of processes of change in individual people who are learning something, solving a problem, or developing a skill [Bidell and Fischer, 1994; Granott, 1993a; Karmiloff-Smith, 1986; Klahr and Dunbar, 1988; Kuhn et al., 1992; Miller and Alosee-Young, in press; Schaub, 1990; Siegler and Crowley, 1991; Wertsch and Stone, 1978]. There seems to be wide agreement that microdevelopmental research will provide important information to illuminate change processes in both learning and development.

Unfortunately, despite this agreement, the current call for microdevelopmental research has stumbled arguably because of the same problems that stymied earlier calls. Because of limited assumptions and methods, researchers have been able to study only a narrow range of tasks and behaviors. As a result, it has been impossible to generalize microdevelopmental analysis to a broad array of human action and thought. Efforts to study microdevelopment have produced only narrow local successes – analyses of some particular task or situation that cannot obviously be applied broadly. Researchers have had difficulty finding a framework for facilitating microdevelopmental analysis of a wide array of learning situations.

**Moving Beyond One-Dimensional Assumptions**

The limitations of prior microdevelopmental analysis arise from a set of assumptions underlying most cognitive-developmental research, assumptions that restrict observation and theory to one-dimensional analysis. When those assumptions are changed, microdevelopmental research expands to encompass a wide range of human action and thought. By limiting developmental observation and explanation to one-dimensional processes, the problematic assumptions have stymied invention of the richly textured framework needed to integrate learning and development. Only by moving to multidimensional-process explanations can short-term change be explained in the same framework as long-term development.
Assumptions that Limit Research

We indicate here three important one-dimensional assumptions that need to be eliminated. Single-person assumption: People learn and develop as individuals, who sometimes interact and influence each other. Contrary to this individualist assumption, people do not function alone in most learning and development. Instead they operate in a fundamentally social way, working together in ensembles [Granott, 1993a] that distribute a task or problem across several collaborating partners [Allport, 1961; Fischer and Bullock, 1984; Vygotsky, 1978].

Single-level assumption: At any one moment a person functions at a single cognitive stage or a single level of complexity. Contrary to this one-level, one-pathway assumption, people function at multiple cognitive levels concurrently, even within the same task or situation [Damasio and Damasio, 1992; Fischer and Ayoub, 1994; Goldin-Meadow et al., 1993; Marcel, 1983; Siegler, 1994, in press]. In development, a person moves through a web of connected pathways composed of multiple strands (domains or tasks), each involving different developmental levels, as shown in figure 1 [Bidell and Fischer, 1992; Fischer and Tangney, 1994]. In addition, there is a diversity of levels within each strand, because every strand in the web is composed of multiple concurrent threads, like a rope or string. Each thread comprises a different dimension of activity within a given task or situation. Together the threads comprise a web within the strand, so that each strand itself constitutes a subsidiary web within the larger web, as illustrated by the enlarged area in figure 1. For example, a problem-solving task may include threads for speaking about the task and for achieving some new understanding in the task. These two threads typically operate at different developmental levels. Microdevelopmental analysis requires differentiation of such threads because only some threads undergo microdevelopment in any one period.
Single-shape assumption: Each developmental pathway shows basically the same shape – linear or at least monotonic increase. Contrary to this linearity assumption, developmental pathways or strands take many different shapes that frequently include reversals in direction – not only increases but also decreases. Growth usually occurs in fits and starts, showing oscillations that are intrinsic to the processes of development [Cooney and Troyer, 1994; Fischer and Rose, 1994; Howe and Rabinowitz, 1994; Lampl and Emde, 1983; Thatcher, 1994; Thelen and Smith, 1994]. Developmental pathways or strands move through nonlinear dynamic patterns of change, not straight lines. Moreover, the several threads within a strand do not develop all of one piece but instead show different developmental pathways that are characterized by different shapes and different directions of change. One common pattern in microdevelopment seems to be regression to a low-level skill followed by construction of a new skill as the person gradually moves toward higher developmental levels [Duncker, 1935/1945; Fischer, 1980a; Granott, 1993a; Karmiloff-Smith and Inhelder, 1974; Kuhn and Phelps, 1982; Miller and Aloise-Young, in press; Werner, 1957].

Microdevelopment along Multiple Concurrent Distributed Pathways

Understanding learning and development together requires moving beyond these assumptions. First, developmentalists need to move from studying how single individuals change to studying how ensembles learn and develop together. People naturally act, learn, and develop socially, acting collaboratively in small groups or ensembles that distribute a task across the members of the group.

Second, developmentalists need to move from assuming a single, common pathway of development toward recognizing that people develop and learn along multiple concurrent strands and threads in a developmental web. Each person, as well as each ensemble, normally has multiple concurrent goals and carries out multiple actions and thoughts in parallel. We naturally act, learn, and develop in many ways simultaneously. This multipathway functioning is evident not only in action and thought but also in neural systems, which naturally operate not as one-dimensional networks but as parallel, multidimensional combinations of networks [Fischer and Rose, 1994; Grossberg 1987, 1988; Rumelhart and McClelland, 1988]. People thus function at different levels in different parts of the developmental web, not at a single level.

Third, developmentalists need to move from assuming that development and learning are linear or monotonic to describing the complex nonlinear fits and starts of actual learning and development. People develop dynamically, showing different complex shapes of growth in diverse strands and threads of the web. Microdevelopment often involves regression to a low level of skill, followed by dynamic movement through a series of spurts and drops that gradually progresses toward higher levels.

In performing an activity, people do not show the same continuous knowledge level from moment to moment. They change formulations of the task, moving among harder and easier understandings. With changes in the immediate context, contextual support for skill varies and exerts powerful effects on level of functioning [Biddell and Fischer, 1994; Fischer et al., 1993]. Even when people seem to be repeating an action or solution under the same conditions, they pay attention to different aspects of the problem or different implications of the solution and so change the way they think about or approach the 'same' problem [Granott, 1993a].

When learning and development are analyzed within an appropriately complex framework that includes parallel, concurrent pathways among collaborating ensembles
of two or more people, the traditional learning/development dichotomies fall away. Instead of asking whether learning or development is primary, researchers can begin to study both within the same framework. To illustrate this kind of microdevelopmental analysis, we describe a problem-solving situation in which a dyad learns about an unfamiliar device.

**Collaborative Microdevelopment in an Ensemble**

Moving beyond the single-person assumption not only leads to more ecologically valid research but can also make microdevelopmental research easier to do. People typically work collaboratively in small ensembles to learn and solve problems together, even though they can act and think without anyone else directly present. Other people are part of the fabric of each person's action and thought, as scholars have argued for the last century [Baldwin, 1894; Bronfenbrenner, 1993; Fischer and Bullock, 1984; Freud, 1923/1961; Gilligan, 1982; Granott, 1993b; Mead, 1934; Vygotsky, 1978; Wittgenstein, 1953].

Social interaction is a propitious context for studying learning and development. The study of change in ensembles is a powerful tool for gathering information about microdevelopmental processes. Processes of learning and problem solving in individuals can be less than transparent to observation. As a solitary child or adult learns something new or solves a problem, he or she typically does not think aloud or furnish other overt clues to unobservable processes of change. When researchers try to study microdevelopment by forcing individuals to think aloud or to interrupt their activity to report on what they are thinking, the natural flow of behavior is disrupted, the ecological validity of findings is compromised, and the social nature of development is lost.

In ensembles, in contrast, partners communicate with each other about what they are learning, how they are conceiving of a problem, and how they are approaching its solution. These communications provide a wide range of information about the processes of change in both the ensemble and the individuals. Thinking processes are exposed through the interaction [Granott, 1993b; Radziszewska and Rogoff, 1988]. Researchers can record the communications and other sources of information and later analyze them in detail. In this way, analysis of microdevelopment is enriched by the study of ensembles, which provide a natural source of information about underlying processes.

Moreover, the study of learning and development as solitary enterprises misrepresents the nature of human knowledge and skill. People naturally act and think socially, even incorporating other people into their frameworks when they are functioning alone. When they are participating in an ensemble, they learn and develop in fundamentally different ways than they would alone, because the members of the ensemble can invent knowledge and skill together that none of the group members could construct alone [Baldwin, 1894; Granott, 1993b; Hatano and Inagaki, 1991; Mead, 1934; Wittgenstein, 1953]. During these natural collaborations, people learn not only from each other but through each other, combining their actions and thoughts to produce a new common product [Tomasello et al., 1993]. This social nature of learning and development is so fundamental that it is embedded within human families and societies. Both rely on socially guided participation to regulate learning and development and to develop knowledge and skill together [Lave and Wenger, 1991; Rogoff, 1993].
Oddly, few researchers have taken advantage of this obvious window on processes of change. One reason for their failure to do so is probably the assumption that individuals are more ‘basic’, as well as easier to study. In our research, contrary to this assumption, observing people in ensembles actually makes microdevelopmental research easier and more natural, providing a wealth of data on processes of change. If the mind is fundamentally social, this ease of observation is not just a fortunate artifact of observation; it reflects the basic nature of ensembles in human development. The ensemble is at least as basic as the individual.

Many researchers have studied the cognitive effects of collaboration, in the cases of both peer and adult-child interaction [Azmitia, 1988; Ellis and Rogoff, 1986; Forman, 1989; Glachan and Light, 1982; Kruger, 1992; Kuhn, 1972; Martinez, 1987; Radziszewska and Rogoff, 1988; Tudge and Rogoff, 1989]. However, researchers have mostly examined individuals’ knowledge before and after collaboration, instead of examining knowledge during the collaborative process itself. Relying on this before/after design, researchers have fallen back on all three problematic one-dimensional assumptions – treating the individual as the primary locus of development, conceiving of only one pathway arising from collaboration, and evaluating all pathways as linear (because two observation points can produce only a straight line).

Analyzing an ensemble’s ongoing coconstruction of knowledge moves research away from these problematic assumptions and offers powerful new tools for investigation. Researchers can observe development and learning as they occur naturally, they can detect several developmental pathways during interactions, and they can detect dynamic, nonlinear pathways through multiple observations of the interactions over time. As a result, the cognitive processes underlying development become much more transparent.

To illustrate, we describe a problem-solving interaction involving two graduate students. Ann and Donald were asked to try to understand the operation of a Lego robot [Granott, 1993a]. About the size of a child’s toy truck, the robot was built from Lego blocks, wheels, batteries, and electronic circuits, and it moved around the floor on its own. Sensors on the robot controlled changes in its movements, responding to changes in sound, light, or touch. A group of eight adults was shown the robot and told nothing about it except that it was called a ‘wuggle’ and that they were to figure out how it operated. The participants grouped themselves spontaneously into ensembles and decided what to do with the robots, focusing on one robot at a time. They worked mostly in groups of two or three and at their own initiatives changed groups periodically throughout the research sessions, which lasted a total of approximately four hours. Ann and Donald worked together closely throughout most of the first session.

As Ann and Donald worked with the robot, their activities and conversations were recorded on video- and audiotape. These interactions afforded rich information about the processes by which the pair learned how the robot functioned. They communicated much information to each other through words and gestures, which could be understood and interpreted from the videotapes and transcripts. Their interactions fell naturally into separate episodes, which coders readily agreed upon. We called these episodes ‘interchanges’.

Each interchange was scored for its level of complexity, based on the rules for complexity analysis of dynamic-skill theory [Fischer, 1980b; Fischer and Farrar, 1987]. Two independent coders analyzed participants’ discourse and actions for each interchange in terms of skill levels for this task. For example, a representational mapping (level 5 in
Fig. 2. Microdevelopment and nondevelopment in two threads of task activities in an ensemble.

Fig. 2) was scored when Ann and Donald related two characteristics or events as cause and effect. They showed one such mapping when they represented the forward and backward movement of the robot arising from its sensor's response light, thus mapping represented light to represented movement. Such codings yielded a skill level for each interchange and thus a series of skill levels for successive interchanges, marking how the ensemble’s reasoning about the robot changed in complexity over time. Figure 2 (lower curve) shows an example of microdevelopment in understanding the robot. This first problem-solving sequence lasted 20 minutes. (The upper curve is discussed below.)

One striking aspect of the growth curve is Ann and Donald’s initial very low level of understanding, indicating a skill level far below that expected of intelligent adults. The two of them came into the situation with no familiarity with Lego robots, and so they began with a low-level understanding of the robot’s functioning. They initially co-constructed their knowledge of the robot through sensorimotor skills, gaining access to the unfamiliar task through basic actions and observations. When their understanding of the device was coded in terms of skill complexity, they showed a clear progression, moving from low-level egocentric actions to more sophisticated actions on the robot and eventually to representations of some of its key properties. This microdevelopmental sequence followed the same progression through skill levels that occurs in long-term development, thus demonstrating a parallelism between micro- and macrodevelopment. Following this sequence, Ann and Donald showed three additional similar sequences as they shifted to different approaches to understanding the robot. In each
casc, they began with egocentric actions and then gradually moved toward represen-
tations.

The movement from low levels to progressively higher ones is a second important
aspect of the growth curve in figure 2. This growth function shows nonlinear, dynamic
microdevelopment, with up-and-down oscillations, gradually moving from simple skills
to increasingly complex actions and representations.

A third impressive aspect of the growth curve is that the progression was shared
across the two members of the ensemble. The collaboration was pervasive. No clear separ-
ation of the two members' contributions was possible. Instead, they were so closely
linked that it was difficult to tell them apart. In figure 2, different symbols indicate inter-
actions in which Donald was the leader (making statements about their knowledge),
those in which Ann was the leader, and those where there was joint leadership. Not only
did they share leadership, with Donald leading 26 times, Ann 32 times, and the two lead-
ing jointly 6 times; their contributions were approximately evenly distributed over the
growth curve. Indeed plots of each individual's leadership episodes showed essentially
the same growth curve as the combination of both of their episodes, as is evident in fig-
ure 2. Ann and Donald truly functioned together as a closely collaborating ensemble,
showing distributed learning.

**Multiple Levels and Diverse Shapes in Developmental Strands and Threads**

People generally function at multiple levels concurrently, even when they are fo-
cusing on one particular task, such as working with a Lego robot. As Ann and Donald
acted on the robot and talked about it together, they sought to understand how it func-
tioned. At the same time, they pursued several other related activities, including com-
municating about their joint efforts, moving themselves around the room with respect to
the robot, and testing hypotheses about the robot. They were thus performing a diverse
set of connected activities involving the robot, each apparently defined by a distinct,
usually implicit goal [Fischer et al., 1990; Frijda, 1986; Granott, 1993a; Lazarus, 1991].
Each of these activities was a separate thread in the strand of their general task of work-
ing with the robot.

Each thread can develop distinctively, with some showing microdevelopment and
others showing very different patterns of change. We analyzed two separate threads in
Ann and Donald's interaction – one for understanding the device (an unfamiliar task)
and a second one for communicating about it (involving familiar skills for conversing),
as shown in the two curves in figure 2. These two threads showed distinct patterns of
change. The upper curve represents the complexity level for Ann and Donald's commu-
ications to each other, as they talked about the robot and their own actions with it.
From the beginning of the session, the skill level of this thread was much higher than
that for understanding the device. It started with complex representations about the
device and it maintained similar high levels throughout the session. In addition to starting
at a relatively high level, Ann and Donald's communication showed no microdevelop-
mental progression. It fluctuated among several levels of relations of representations,
and the only sign of advance was a movement to elementary abstractions for a few
events near the end of the episode.

The thread for understanding the device, in contrast, showed strong microdevelop-
mental progression, as described earlier. It began at a very low level of functioning – sin-
gle egocentric actions - and moved gradually toward more complex actions and eventually representations of characteristics of the robot.

In videotapes of subjects like Ann and Donald, observers quickly see the high level of communication, including its clear use of representations as reflected in words such as gadget, wheel, start, go, react, noise, sound, and light. For example, as Ann and Donald began to work with the robot at the start of the session, Ann said the following to Donald (note that the truncated, incomplete nature of the statements is typical in this kind of learning situation):

I tried to experiment with it if it would ... Now I've broken it, hmm ... if it would react if it's hitting the ...

In these statements, as well as her accompanying activities, Ann represented herself experimenting with the robot, and she also represented the robot as broken, reacting, and hitting something. The complexity for this observation in figure 2 was level 6.5 (interchange No. 5, top curve).

Later in the session, Ann and Donald showed a similar level of representation in their talk about the effect of sound on the robot:

Ann: Maybe we should try behind it and in front of it. I mean, we're considering that's the front...

Donald: Did it go?

... Yeah, that's all. Yes, all of those have worked.

Here they were representing their own actions, as well as the front and back of the device with respect to the sound. The complexity for this observation in figure 2 was level 6 (interchange No. 48, top curve).

As these examples illustrate, the generally high skill level of Ann and Donald's thread for communication consistently involved relations of representations (skill levels 5 and 6). If an observer's focus remained on this one thread, he or she would see no microdevelopment in Ann and Donald's learning. To detect microdevelopment, the focus needs to shift to the thread discussed earlier - understanding of the device.

The growth curve for understanding the robot deals with how Ann and Donald gradually developed from egocentric actions on the robot to informed representations of its properties. This important thread shows clear microdevelopment: at the start Ann and Donald showed egocentric actions and poor knowledge of the robot; by the end, they demonstrated a reasonable representation of some of its properties.

Even though Ann and Donald started out using complex representations in their communication, they evidenced egocentric confusion in their understanding of the device. They did not differentiate between characteristics of the robot and their own influence on those characteristics, and they misunderstood the most basic properties of the robot. In the first quote, Ann stated that she had broken the robot, when her actions in fact had had no effect on it at all. She went on to suggest that the robot's reaction depended on the direction of the stimulus, which was also incorrect. Although she and Donald were using representations to communicate, their understanding of the robot was at the level of egocentric actions, because they confused the effect of their own actions with those of the robot and misrepresented the robot's actual actions and characteristics. The same activity that was at skill level 6.5 for communication was far down the complexity scale for understanding the device - at level 1.5 (interchange 5 in fig. 2, both curves). Ann and Donald used representations to communicate, but they did not yet understand the most basic actions and perceptual characteristics of the robot's functioning.
Later in the session, their understanding of the device had advanced substantially. In the second quote, they had experimented to build a complex system relating several actions and perceptions. They could now relate variations in the loudness and distance of the sounds they aimed at the robot with changes that they saw in its movement. The interchange showed skill level 3.5, a substantial development from 1.5 in the earlier episode. Ann and Donald were on the verge of forming a simple representation of the device as sensing and reacting to sound. A few interchanges later, a full representation emerged, as indicated by Donald's proposal that the robot responded to a quality of sound:

Because maybe you could just evaluate the sound, and if the sound met some criteria, that's an on. If the sound didn't meet some criteria, that's an off.

For exactly the same interchanges with the device, Ann and Donald showed two different threads characterized by different levels of functioning and distinct growth patterns. The microdevelopment apparent in the growth of understanding the robot (lower line) was absent from the thread for communicating with each other (upper line).

**Conclusion: Putting Learning and Development Together**

When people learn a task or solve a problem, they normally work in collaboration with others in ensembles, and they function at several distinct levels of complexity based on separate threads or goals in an activity. Examining people's interactions during their collaborations greatly facilitates analysis of the processes behind learning and development. Both verbal exchanges and joint activities among ensemble members expose cognitive processes for observation. At the same time, analysis of the interactions captures the fundamentally social nature of human development – people co-constructing their knowledge, supporting each other and learning jointly.

Distinguishing the separate threads in an activity makes it possible to detect where microdevelopment (short-term growth or improvement) occurs and where there are other kinds of change patterns. In the present case, one thread is based on the goal of understanding the unfamiliar device, and another is based on the goal of communicating about the task. The two threads show distinctive patterns even though both are contained in the same activities. The thread for understanding shows initial regression to a low skill level followed by clear microdevelopment to increasingly complex levels that parallel long-term development. In contrast, the thread for communication shows a high level from the start and does not progress. Thus, microdevelopment can be detected only when the threads are carefully distinguished. A superficial analysis that focused on communication would not detect the genuine microdevelopment in understanding.

When researchers move beyond the one-dimensional assumptions of single individuals, single levels of functioning, and linear growth curves, they gain new power for analyzing learning and development. Short-term changes involved in learning and problem solving (microdevelopment) can be analyzed within the same framework as the long-term changes involved in development (macrodvelopment). Analyzing multiple threads in the learning and problem solving of collaborating ensembles will eventually show that learning and development comprise the same basic processes of change in knowledge and skill.
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