A New Kind of Developmental Science:

Using Models to Integrate Theory and Research

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This monograph heralds a new era in developmental research. New tools make it possible to build more powerful, grounded assessments and to use them to empirically test complex developmental models, potentially producing a quantum leap in developmental research. For over a hundred years, psychology has been marked by grand, elaborate theories of developmental process and structure, such as those of Baldwin (1894), Bruner (1956), Freud (1909/1955), Hebb (1949), Piaget (1936/1952; 1983), Vygotsky (1978), and Werner (1948); but until recently research methods have not been up to the task of testing these sophisticated theories.

The situation has changed radically in recent years, as advances in developmental scaling and model testing, along with powerful computers, have made it possible to embody complex theories in explicit models and to test them with carefully scaled assessments (Dawson, 2002; Fischer & Bidell, 1998; Lerner, 1998; van Geert, 1991, 1998; Willett, 1997). Experimental and theoretical work can be integrated in a new way that was difficult or impossible twenty years ago. With these new tools, most of the perennial debates in developmental science can change from endless, unresolvable arguments that amount to little more than asserting differing positions. For example, the stage debate has vacillated between "Development occurs in stages" and "No, it doesn't. It's continuous." These arguments can be transformed by building explicit models that can be tested empirically and that reformulate the old arguments: For the stage debate, a model now specifies how and when development shows staged growth patterns and how and when it shows continuous patterns (Dawson, Commons, & Wilson, under review; Fischer & Kennedy, 1997). In many such cases, the debates can be resolved by integration of apparently opposing explanations in a model of relations between complementary processes of development.

Relating Efficiency, Memory, and Structure

In this monograph Demetriou, Christou, Spanoudis, and Platsidou (who we will refer to in short form as simply "Demetriou") have produced one of the most ambitious efforts to realize this emerging paradigm, using some of the new tools to connect constructs from different frameworks for cognitive development. The primary debates addressed involve relations between processing efficiency, working memory, and cognitive structure (which Demetriou often calls problem solving). Instead of treating these processes as opposing explanations, the authors combine them in a single study in order to unpack how the processes relate to each other in development of 8- to 14-year-old children.

They have done an exciting, important service for developmental science, setting forth a complex, multidimensional, hierarchical model of the "architecture of the mind" that integrates three distinct perspectives (information processing, differential psychology, and neo-Piagetian developmental theory) in a combined cross-sectional, longitudinal design. This project shows how developmental scientists can assess concepts from multiple frameworks and relate them through explicit modeling and targeted research. In this way researchers can begin to build explanations that are powerfully grounded in the best combination of data and theory.

This ambitious study links measures from each tradition and analyzes the measures with sophisticated modeling tools to empirically assess the relations among the constructs from the models. The results demonstrate the usefulness of the sophisticated combination of psychometric assessment with explicit mathematical modeling to build a new generation of tools for developmental science. They illustrate how the new tools for modeling and assessment can bring together previously disparate branches of development, making possible the new kind of approach that several scholars have been calling for (Fischer & Bidell, 1998; Gottlieb, Wahlsten, & Lickliter, 1998; Lerner, 1998; Overton, 1998; van Geert, 1998). The three different processes relate to each other, each contributing to growth patterns in distinctive ways.

On the other hand, as in any new enterprise, this project also highlights challenges in using the new tools. To employ the new assessment and modeling tools most effectively to advance understanding of development requires careful construction of scales to measure concepts and careful specification of models in relation to the processes being tested. We are not convinced of the authors' specific conclusions because of important issues about their design of developmental scales and their use of models.

Developmental Rulers

To measure length, a ruler needs to be carefully constructed, with regular intervals demarcated and measurement procedures standardized. To measure volume, the multidimensionality (three dimensions multiplied together) make the accuracy of the ruler and the carefulness of the procedures even more important. A major factor that has limited the use of new modeling tools in developmental research has been the absence of well constructed rulers for cognitive processes (Rose & Fischer, 1998). Without common, well constructed measures, it is not even possible to know whether two researchers studying, say, memory development, are even talking about the same thing. Researchers know how to measure speed and location of movement, which provide good measures for examination of motor development (Thelen, 1995). For constructs such as working memory, processing efficiency, and cognitive structure, no such easy measures exist. Researchers need to carefully construct rulers to be able to measure these constructs, test their growth functions, and use the models of the new paradigm. This issue of constructing rulers pervades the Demetriou study.

Creation of a ruler for a developmental construct requires carefully devising and testing items and administration procedures and testing scale properties. Only after such careful work can a scale be used effectively in a study to test a multidimensional model. Until recently, the idea of developing rulers for developmental constructs appeared unrealistic, because the constructs can be conceptually slippery, complex, multidimensional, and subject to contextual biases (Fischer, Rotenberg, Bullock, & Raya, 1993b). That is why there are not yet any universally recognized and accepted developmental measures. This problem, which is common in the early development of any scientific discipline, is magnified by the psychological nature of concepts such as working memory and cognitive structure, which are based not on physical characteristics of action but higher-order descriptions of the organization of action.

The situation is reminiscent of the measurement of length, size, temperature, and time prior to the establishment of universally agreed-upon units and procedures. People agreed that temperature was a useful construct, and that there were broad general criteria that could be used in its assessment, such as freezing water and melting ice, boiling water, feeling hot or cold, and so forth. Measurement began with the most consistent observable referents, such as the melting of ice and the boiling of water, and was extended to referents that show some consistency, such as when people feel cold, when they feel hot, when they shiver, when they sweat profusely. But these events delineate relatively large units of temperature and so mark only a beginning for measurement. Until researchers agreed upon the units and procedures for measuring temperature, they had no satisfactory means of coordinating their observations in various locations and positions.

The same situation applies in developmental measurement. People recognize that development is a useful construct and that there are important differences in the thinking of infants, children, adolescents, and adults. At the same time, there has been no agreement about the units of development and no satisfactory way of coordinating observations of development across domains and contexts. Researchers can potentially agree upon a few observable referents. Development begins with birth and ends with death, there are developmental “milestones” interspersed along the way, such as walking, speaking sentences, puberty, and having children. Though these points, like melting point, boiling point, feeling cold, and feeling hot, represent relatively large units that are limited in their utility, they can form the basis for beginning to build a developmental ruler.

Recent advances in psychometrics in general and developmental assessment in particular have allowed developmentalists to move beyond this beginning to build better rulers for important developmental constructs. One such ruler relevant to the Demetriou study examines cognitive-developmental complexity as marked by discontinuities in growth (fits and starts, jumps and gaps). Cognitive performances such as those being examined in this study can be usefully characterized in terms of a limited number of developmental levels marked by discontinuities that show considerable consistency across tasks, contexts, and children (Dawson, 2002; Dawson et al., under review; Fischer & Bidell, 1998; Fischer et al., 1993b). The levels of activities vary under some conditions, just as water freezes at different temperatures when it has mud in it, when it is mixed with alcohol, when it is under increased or decreased atmospheric pressure, and so forth. When assessed with consistent procedures and especially under conditions designed to stabilize and optimize performance, however, development shows a systematic series of discontinuities, which we call levels or stages.

These levels provide fine calibration for a developmental ruler for cognitive development, defining subunits on the ruler – the degrees of development. This kind of ruler was not used in the current study, although the authors did perform an intuitive analysis of their tasks and suggest relations to this scale. The specific levels and the grain of coding have not been tested in scale construction, and they seem to vary with different items and scales. Variations in levels assessed and grain of coding have important effects on findings, especially in a multidimensional model.

Another kind of ruler that has been finely developed in prior research is working memory. Case, Baddeley , Halford, and others have done extensive research constructing rulers to measure working memory, some focused on development (Case, 1991; Case, 1992; Halford, Wilson, & Phillips, 1998) and some focused on variation in performance in adults (Baddeley, 1990). Scales vary with different content and assessment conditions, and items must be carefully tested to assure a good ruler. For the most part, Demetriou did not use these research-based rulers to assess working memory.

What are the important properties of a good measure or ruler? A consensual definition is that a measure (a) addresses a single trait, (b) applies to multiple samples, (c) produces reliable assessments that are independent of the particular items in one instrument, and (d) has interval units, not merely ordinal ones (Bond & Fox, 2001; Fisher, 1994; Luce & Tukey, 1964; Masters, 1988; Michell, 1999; Narens & Luce, 1993; Wang, Wilson, & Adams, 1996). Measures with these qualities are required to meaningfully model developmental processes.

Researchers can rely on the rulers established in prior scaling research, or they can build their own rulers by using the new methods that facilitate such construction. First, researchers must carefully define a construct or dimension and its assessment context. Second, tasks and items must be tested to determine how people perform them and whether performance is consistent. Highly variable performance can be interesting in its own right, but analyzing it requires a different approach, focusing on the cognitive dynamics (see Fischer & Bidell, 1998; Fischer, Knight, & Van Parys, 1993a; Siegler, 1994). Third, classical Guttman scaling tests the sequentiality of tasks to determine which tasks form linear orderings (Fischer et al., 1993a; Guttman, 1944; Wohlwill, 1970). Factor analysis and related techniques test whether tasks form a coherent domain or divide into different domains. Fourth, Rasch analysis tests the specific scaling of items (and people) in a domain, assessing the intervals between items, gaps in the scale (demarking levels), and other scale properties (Bond & Fox, 2001; Rasch, 1980).

In practice, these four steps do not form a simple linear pattern but involve a discursive process. Based on theoretical notions researchers produce a tentative definition of a domain or construct. They then collect empirical evidence about performance within the domain, including specification of the strategies that individuals actually use to perform the tasks. For example, in developmental assessment, an item should not be solvable with a strategy that is less developmentally advanced than the targeted strategy or skill. To build a good ruler, all new items must undergo extensive testing. Procedures are helpful that ask older children and adults to think aloud as they perform a task. Items can be identified through observation and scaling assessment that can be solved with multiple strategies or that are performed differently from what was intended. Once identified, these items can be refined with further research to determine whether they can be improved or whether they show something interesting or important.

This kind of scale development is especially important in a study like the present one, because each battery is of necessity made up of very few items. Under these conditions, every single item must be a good indicator of the construct. The iterative test design process advances theory in two ways. First, it provides accurate, reliable measures that can be widely employed to test constructs. Second, it aids in refinement of constructs through assessment of dimensionality. Does a ruler measure one dimension, or does it measure several combined dimensions? Recent projects employing the Rasch model to validate developmental assessments present a rigorous approach to the construction of developmental measures (Bond & Fox, 2001; Dawson, 2002; Fisher, 1994). Because the computer programs employed to conduct Rasch analyses provide highly detailed information about item, person, and scale functioning, they are ideally suited for this application.

As a discipline, cognitive developmental science now has the tools to establish agreed-upon scales for major constructs – the construction of reliable and accurate developmental assessments and eventually, genuine developmental rulers. Good measurement has an enormous impact on theory development, for it is only when we can measure a construct reliably, accurately, and repeatedly that we can rigorously examine models and explanations.

The importance of good measurement is even greater in research with models because the multidimensionality of models like that in the Demetriou study increase error. Typically, error increases exponentially as the number of dimensions increases. A small error in the calculation of length, for example, magnifies into a large error in the determination of volume. Because of the enormous increase in the effects of error, the requirement for good measures increases greatly in studies that use models to test relations among constructs.

Using Models of Development

In the new kind of developmental science, methods and theories are integrated through the use of good rulers for multiple constructs in appropriately complex developmental models. Research does not stop with one model, however. Most developmental theory requires several kinds of models for a thorough test of constructs. Demetriou provides a strong example of this process by using structural equation modeling, linear growth modeling, and a simple form of dynamic growth modeling to examine processing efficiency, working memory, and cognitive structure in development. Complex dynamic systems models are a fourth kind that is important for the new developmental science. Different kinds of models can answer different questions about the nature of cognitive development.

First, structural equation modeling has become the most widely used form of explicit model testing in developmental science (Kaplan, 2000). Based on linear regression, it is a valuable tool for comparing different models of linear relations among measures and/or constructs. Demetriou and his colleagues use it appropriately to test their model of linear relations among processing efficiency, working memory, and cognitive complexity. They find that their model is supported. From their analyses, they report many interesting findings, such as that processing efficiency apparently predicts long-term development of cognitive structure (problem solving) better than does working memory.

Along with its strengths, the monograph illustrates two of the difficulties that investigators encounter in multidimensional modeling. The first difficulty is that sketchily defined rulers obscure the clarity of interpretation of findings. For example, the finding that processing efficiency predicts long-term development best, and apparently accounts for cognitive structure statistically, is interesting and potentially important. However, the finding may results entirely from the difference in the quality of the rulers for processing efficiency, working memory, and cognitive structure. Based on the statistical properties of the measures and their grounding in prior measurement research, the best ruler seems to be processing efficiency, the next best seems to be working memory, and the fuzziest seems to be cognitive structure (because they were not pretested and scaled and they were based only loosely on prior research).

The second difficulty is that complex multidimensional modeling demands relatively large sample sizes. Structural equation modeling optimizes effect sizes, and consequently, low sample sizes (low power) can produce unreliable path estimates. That means that low sample sizes can produce inappropriate matches with a model, rejecting the null hypothesis when it should be accepted. The result is that models are "confirmed" because of small sample sizes.

Happily, there is a straightforward solution to the need for larger sample sizes: The difficulties and expenses of obtaining large samples can be overcome by use of the same sound measures across studies (Dawson, 2002). Then researchers can pool data from independently conducted studies to obtain large sample sizes and facilitate testing of multidimensional models.

Structural equation models are not optimal for asking many developmental questions because of their linear assumptions and their lack of focus on patterns of change. Fortunately other powerful new tools are available that are specifically designed for developmental research (Singer & Willett, 2003; Willett, 1997). The simplest developmental tool is the linear growth model, including latent growth models, which are structural equation models modified to apply to questions of growth (Duncan, Duncan, Strycker, & Li, 1999). Growth models use the growth function of each person as a unit in analysis, as illustrated by Demetriou's analysis of children's different types of growth curves (Chapter 5). Demetriou and his colleagues use latent growth models to test the linear growth properties of their major measures, and other researchers should follow their lead. Growth analysis should be a basic part of developmental research.

The third kind of model used by Demetriou moves away from the assumption of linear growth, recognizing that most development involves nonlinear change arising from the dynamics of growth (Fischer & Bidell, 1998; Overton, 1998; Siegler, 1994; van Geert, 1994). Logistic growth analysis takes a first step toward nonlinear growth analysis by starting with logistic growth rather than linear growth (van Geert, 1991). Logistic growth is based on the standard equation for growth used in the biological sciences, in which the basic curve is S-shaped rather than linear. The logistic function is fundamental and represents growth more accurately than linear growth, especially for individual as opposed to group curves. By using logistic growth models, Demetriou can examine curvilinear growth functions, as is evident in the logistic curves in Figures 22, 23, and 24. He thus moves his models closer to the basic form of growth and begins the process of analyzing the complex growth functions of individual students.

Logistic growth points to a fourth set of powerful tools for developmental research – dynamic growth modeling. Like most specific models of development, Demetriou's models for cognitive development make clear predictions about individual growth, not only about group means. Demetriou's statistical tools focus on group patterns, but growth modeling moves the analyses toward individual growth by taking each person's growth curve as the basic unit.

Individual growth typically shows complex, dynamic change, often even more complex than in Figures 22-24. When complex individual growth curves are averaged across many children, a smooth curve typically results, but that curve does not accurately represent the patterns of individual growth (Estes, 1956; van der Maas & Molenaar, 1992). Dynamic growth models eliminate the linear assumption of most statistical analyses and allow growth patterns to take complex forms. The spurts and plateaus of development of cognitive complexity illustrate the complexities of dynamic growth, and they are generally more striking and obvious in individual growth curves than in group curves (Fischer & Bidell, 1998). The complexity of those forms provide rich data to explicate the processes of growth and to test complex growth models (Rose & Fischer, 1998; van Geert, 1994). An important research paradigm for the new developmental science is dense collection of longitudinal data on individuals over short time periods to assess developmental processes in individual growth (Yan & Fischer, 2002). In their next study, perhaps Demetriou, Christou, Spanoudis, and Platsidou can add the rich tools of dynamic modeling to the new form of developmental science that they are helping to pioneer.

Conclusion

In this important study Demetriou, Christou, Spanoudis, and Platsidou point the way to a new era in developmental research in which models and data are combined to build explanations worthy of the rich traditions of developmental theory. The requirements for this new kind of research include large-scale data sets with a longitudinal component and explicit mathematical models of important developmental constructs. The large-scale data sets can be collected in several ways: (a) ambitious studies like the present one that combine longitudinal and cross-sectional data, (b) combinations of data from different studies that use common methods and scales (Dawson, 2002), or (c) densely collected longitudinal data on individuals that allow multidimensional modeling of development and learning in individuals (van Geert, 1991; Yan & Fischer, 2002).

The use of explicit mathematical models to ground and test developmental theory is greatly facilitated by new computer-based tools for multidimensional modeling: structural equation modeling, individual growth modeling, and dynamic systems modeling (including logistic growth). Effective research with these models requires carefully constructed rulers for the developmental constructs. Creation of such rulers involves testing of items and scale properties before collecting data to test models. Guttman (1944) scaling and Rasch (1980) scaling provide valuable tools to facilitate the construction of sound rulers and avoid difficulties with interpretation of findings, which are magnified by scaling problems in multidimensional models.

With these new tools for scaling and modeling, developmental science can move beyond arguments pitting complimentary perspectives against each other and build a more powerful, effective field grounded in strong data and explicit theory that is appropriately complex for representing the processes of development. Instead of arguing for processing efficiency, working memory, or cognitive complexity as alternative explanations of cognitive development, we can examine all three constructs in the same models and analyze how they influence each other and contribute to development, as Demetriou and his colleagues have done. Instead of arguing about whether development occurs in stages or continuous functions, we can examine when growth has stage characteristics and when it is continuous (Fischer & Bidell, 1998). Instead of arguing about whether development follows Piaget's (1975/1985) individual equilibration process or Vygotsky's (1978) social support process, we can combine the two processes in a model that specifies how both individual learning and social support shape development (van Geert, 1998). What an exciting future we face as we join data with models to build the new developmental science!

References

Baddeley, A. D. (1990). Human memory: Theory and practice. Hillsdale, N.J.: Erlbaum.

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

Bond, T. G., & Fox, C. M. (2001). Applying the Rasch model: Fundamental measurement in the human sciences. Mahwah, N.J.: Erlbaum.

Bruner, J. S., Goodnow, J. J., & Austin, G. (1956). A study of thinking. New York: Wiley.

Case, R. (Ed.) (1991). The mind's staircase: Exploring the conceptual underpinnings of children's thought and knowledge. Hillsdale: Erlbaum.

Case, R. (1992). The role of the frontal lobes in the regulation of cognitive development. Special Issue: The role of frontal lobe maturation in cognitive and social development. Brain & Cognition, 20(1), 51-73.

Dawson, T. L. (2002). New tools, new insights: Kohlberg's moral reasoning stages revisited. International Journal of Behavior Development, 26, 154-166.

Dawson, T. L., Commons, M. L., & Wilson, M. (under review). The shape of development.

Duncan, T. E., Duncan, S. C., Strycker, L. A., & Li, F. (1999). An introduction to latent variable growth curve modeling: Concepts, issues, and applications. Mahwah, N.J.: Erlbaum.

Estes, W. K. (1956). The problem of inference from curves based on group data. Psychological Review, 53, 134-140.

Fischer, K. W., & Bidell, T. R. (1998). Dynamic development of psychological structures in action and thought. In R. M. Lerner (Ed.), & W. Damon (Series Ed.), Handbook of child psychology: Vol. 1. Theoretical models of human development (5th ed., pp. 467-561). New York: Wiley.

Fischer, K. W., & Kennedy, B. (1997). Tools for analyzing the many shapes of development: The case of self-in-relationships in Korea. In E. Amsel & K. A. Renninger (Eds.), Change and development: Issues of theory, method, and application (pp. 117-152). Mahwah, N.J.: Erlbaum.

Fischer, K. W., Knight, C. C., & Van Parys, M. (1993a). Analyzing diversity in developmental pathways: Methods and concepts. In W. Edelstein & R. Case (Ed.), Constructivist approaches to development. Contributions to Human Development, 23, 33-56. Basel, Switzerland: S. Karger.

Fischer, K. W., Rotenberg, E. J., Bullock, D. H., & Raya, P. (1993b). 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. The Jean Piaget symposium series. (pp. 93-117). Hillsdale, N.J.: Erlbaum.

Fisher, W. P., Jr. (1994). The Rasch debate: Validity and revolution in educational measurement. In M. Wilson (Ed.), Objective measurement (pp. 36-72). Norwood, NJ: Ablex Publishing.

Freud, S. (1955). Analysis of a phobia in a five-year-old boy (J. A. Strachey, Trans.). In J. Strachey (Ed.) Standard edition of the complete psychological works of Sigmund Freud (Vol. 10, pp. 3-152). London: Hogarth Press. (Originally published, 1909).

Gottlieb, G., Wahlsten, D., & Lickliter, R. (1998). The significance of biology for human development: A developmental psychobiological systems view. In R. M. Lerner (Ed.), & W. Damon (Series Ed.), Handbook of child psychology: Vol. 1. Theoretical models of human development (5th ed., pp. 233-274). New York: Wiley.

Guttman, L. (1944). A basis for scaling qualitative data. American Sociological Review, 9, 139-150.

Halford, G. S., Wilson, W. H., & Phillips, S. (1998). Processing capacity defined by relational complexity: Implications for comparative, developmental, and cognitive psychology. Behavioral and Brain Sciences, 21, 803-864.

Hebb, D. O. (1949). The organization of behavior. New York: Wiley.

Kaplan, D. (2000). Structural equation modeling: Foundations and extensions. Thousand Oaks, CA: Sage Publications.

Lerner, R. M. (Ed.) (1998). Theoretical models of human development. In W. Damon (Ed.), Handbook of child psychology (vol. 1) (5th ed.). New York: Wiley.

Luce, R. D., & Tukey, J. W. (1964). Simultaneous conjoint measurement: A new kind of fundamental measurement. Journal of Mathematical Psychology, 1, 1-27.

Masters, G. N. (1988). Measurement models for ordered response categories. In R. Langeheine & J. Rost (Eds.), Latent trait and latent class models (pp. 11-29). New York: Plenum Press.

Michell, J. (1999). Measurement in psychology: A critical history of a methodological concept. New York, NY, USA: Cambridge University Press.

Narens, L., & Luce, R. D. (1993). Further comments on the “nonrevolution” arising from axiomatic measurement theory. Psychological Science, 4, 127-130.

Overton, W. (1998). Developmental psychology: Philosophy, concepts, and methodology. In R. M. Lerner (Ed.), & W. Damon (Series Ed.), Handbook of child psychology: Vol. 1. Theoretical models of human development (5th ed., pp. 107-188). New York: Wiley.

Piaget, J. (1952). The origins of intelligence in children (M. Cook, Trans.).New York: International Universities Press. (Originally published, 1936).

Piaget, J. (1985). The equilibration of cognitive structures: The central problem of cognitive development (T. Brown & K. J. Thampy, Trans.).Chicago: University of Chicago Press. (Originally published, 1975).

Piaget, J. (1983). Piaget's theory. In W. Kessen (Ed.), & P. H. Mussen (Series Ed.), Handbook of child psychology: Vol. 1. History, theory, and methods (pp. 103-126). New York: Wiley.

Rasch, G. (1980). Probabilistic model for some intelligence and attainment tests. Chicago: University of Chicago Press.

Rose, S. P., & Fischer, K. W. (1998). Models and rulers in dynamical development. British Journal of Developmental Psychology, 16 (Pt 1), 123-131.

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

Singer, J. D., & Willett, J. B. (2003). Analyzing longitudinal data. New York: Oxford University Press.

Thelen, E. (1995). Motor development: A new synthesis. American Psychologist, 50, 79-95.

van der Maas, H., & Molenaar, P. (1992). A catastrophe-theoretical approach to cognitive development. Psychological Review, 99, 395-417.

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. London: Harvester Wheatsheaf.

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

Vygotsky, L. (1978). Mind in society: The development of higher psychological processes (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Trans.). Cambridge MA: Harvard University Press.

Wang, W.-C., Wilson, M., & Adams, R. J. (1996). Rasch models for multidimensionality between items and within items. In M. Wilson, G. Englehard, & K. Draney (Eds.), Objective measurement IV: Theory into practice.Norwood, NJ: Ablex.

Werner, H. (1948). Comparative psychology of mental development. New York: Science Editions.

Willett, J. B. (1997). Measuring change: What individual growth modeling buys you. In E. Amsel & K. A. Renninger (Eds.), Change and development: Issues of theory, research, and application (pp. 213-243). Mahwah, N.J.: Erlbaum.

Wohlwill, J. F. (1970). Methodology and research strategy in the study of developmental change. In L. R. Goulet & P. B. Baltes (Eds.), Life-span developmental psychology: Research and theory (pp. 149-191). New York: Academic.

Yan, Z., & Fischer, K. W. (2002). Always under construction: Dynamic variations in adult cognitive development. Human Development, 45, 141-160.