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Putting the process in developmental processes

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Several signs point to a strengthening of our capabilities for rigorously modelling developmental processes and other kinds of changes. The indicators of progress range from stronger formulations of "systems thinking" and definitions through measurement and design considerations to advanced mathematical representations, such as linear and nonlinear dynamical systems models. We believe these advances offer major improvements for the treatment of process and related concepts as they have evolved thus far largely within the meta-model of stability and equilibrium that has dominated much of science (Holling, 1973). These issues are summarised and some of the promising innovations that we believe will make the coming decades highly productive ones for the study of development will be discussed.

The concept of *process* is the "legal tender" of a developmental science. Methodological approaches that have some currency in the study of developmental processes include interventions, age simulations, and longitudinal research designs and their attendant mathematical and statistical modelling. The primary focus of this article is on the latter approach. Somewhat ironically, we believe that without better defining *process* and improving the way we measure, model, and manipulate it, the study of behavioural development will enter the new millennium facing the retardation, if not arresting, of its own development.

Much of developmental research now involves repeated measurements; in principle, if not in fact. As significant as this orientation is and as valuable as longitudinal data are now believed to be, this "victory" will remain a narrow one until the fundamental ways we attempt to conceptualise and model process information rest more heavily on a *bona fide* change orientation and its attendant concepts (Nesselroade & Featherman, 1997). Until then, we believe that even using the currently prevalent, more sophisticated and powerful tools of longitudinal methods (see e.g., Collins & Horn, 1991; Collins & Sayer, in press) that the deeper, richer lodes of developmental phenomena can be mined only superficially.

Depictions of occasion-to-occasion and age-to-age average changes and the stability of rank order (e.g., as in using test-retest correlation coefficients), interesting though they may be from a descriptive point of view, can point to process in only limited ways. In many cases, the measurement occasions are begun, spaced, and end arbitrarily and the descriptions they afford of what is transpiring are just as arbitrary. Indeed, when and how processes start and end are probably the wrong questions for developmentalists to be asking at this point. Rather, some sound description is needed, but it needs to apply to process rather than simply to a sequence of measurements that may or may not represent process in any useful way. The distinction underlying these comments is that between static and kinematic models, on the one hand, and dynamical ones on the other. Plotting the mean scores on *Conscientiousness* for adolescents in 1980, 1990, 2000, and 2010 may be informative about that cohort at those occasions of measurement but it does not inform about their likely scores in 2020 (except by crude extrapolation). Building a model that predicts scores at Time t from scores at Time t_1, offers a basis for predicting at least one step ahead.

It is not just a problem of failure to capitalise fully on existing methods. Obviously, the full capability of a method and the customary or traditional ways it is applied can be quite different. But even when exploited to their fullest, static and kinematic models do not capture the dynamical information that resides in repeated measurements. P-technique factor analysis, for example, was welcomed as the multivariate way to study within-person changes (Bereiter, 1963; Cattell, 1963). Despite its promise in focusing on intensive, frequent observations of the single case, however, it ignored the information resident in serial- and cross-correlations of variables. It took a fundamentally different approach to defining and specifying the factor model for analysing repeated measurements of the single case—dynamic factor analysis discussed later—to be able to exploit the lagged relationships inhering in such single subject data.

In developmental research, it is in the arena of modelling *process* that the interfacing of methodology and substantive theory has become most critical. Giving deeper, more substantial meaning to the label *process* is going to require the use of more powerful methods of measurement, analysis, and modelling than have hitherto generally been applied in developmental research. Despite any current methodological deficits, we believe that systems approaches to studying developmental phenomena (e.g., Ford, 1987; Ford & Lerner, 1992; Thelen & Smith, 1994) with their strong emphasis on the integrated, functioning organism (see e.g., Baltes, 1997; Bergman, 1998; Bergman & El-Kouri, 1999; Cairns, Bergman, & Kagan, 1998; Magnusson, 1995) offer great promise as one of the classes of possible frameworks within which to

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strengthen the theory/methodology interface to the improvement of both kinds of endeavours. This confidence is inspired, in large part, by the intrinsically fundamental status of change and variability in living systems formulations. The patterns of intra-individual changes within systems and subsystems that are most interesting, from our perspective, as developmentalists seek to strengthen the study of process, are the intrinsic dynamics of the ensemble of variables under scrutiny.

In an earlier explication of key methodological issues at the developmental theory/methodology interface, Nesselroade and Ford (1987) described a view of development that incorporated elements of living systems (e.g., Ford, 1987) as well as general lifespan developmental principles (e.g., Baltes, 1987; Baltes, Reese, & Nesselroade, 1977). From this perspective, the general focus of developmental research and theorising is on how individuals retain coherent patterns of organisation and functioning within and across contexts and time. Individuals accomplish this by maintaining consistency in patterns of intra-individual variability across those contexts and time (see also Shoda, Mischel, & Wright, 1993). Modelling these patterns of intra-individual variability as well as studying inter-individual differences and similarities in them is a central goal of developmental research and provides context for further discussion of methodological issues.

Intrinsic dynamics

The label *intrinsic dynamics* signifies that previous states of the system predict future states (Boker & Nesselroade, 1999). This temporal organisation of events simply cannot be modelled well with purely static representations. One can talk in terms of test-retest coefficients and similar indices or even modal trajectories or pathways but these forms do not begin to capture the complexity and richness of the interrelationships.

One sees evidence of "hunger" for more effective ways to come to grips with *process* in many areas of psychology. For example, in personality research even staunch advocates of the structural promise of trait systems, such as the "big five", report the need to advance to more process-oriented conceptions (McCrae & Costa, 1996). Other personality researchers who have been strongly critical of traditional trait formulations (e.g., Mischel, 1968) see a prominent place for "consistency" in behaviour when it is conceptualised as patterning of intra-individual variability—a key manifestation of process—defined across situations (Shoda et al., 1993). For example, repeating a particular sequence of situations would dependably elicit a particular pattern of intra-individual variations in behaviours across those situations, thereby demonstrating consistency of behaviour across situations—not the *same* behaviour across different situations but a consistent pattern of changes in behaviour across situations.[1]

Nevertheless, we hasten to make the point that "dynamic" representations do not diminish or preclude the value that has accrued to static, structural constructions. A case in point is human abilities. These are usually taken to be stable, inter-individual differences dimensions and within this orientation there is a long history of measurement instrument development and predictive validation studies that many would agree have amply justified the investment. Even in these domains, however, salient intra-individual variability (change) aspects of human abilities have been demonstrated by a number of investigators (e.g., Hampson, 1990; Horn, 1972).[2]

One of the clear challenges facing a systems orientation is to better integrate these "stable" and "varying" manifest aspects of abilities. Surely, they are providing alternative views of a single, underlying phenomenon.

It is our belief that major improvements in the way *process* is conceptualised and modelled in developmental research are going to occur through the application of dynamical models to "living systems" formulations (e.g., Ford, 1987; Ford & Lerner, 1992). One already sees indications that developmentalists are moving in this direction (e.g., Thelen & Smith, 1994; van der Maas and Molenaar, 1992; van Geert, 1991) as are other subdisciplines of psychology (e.g., Fitzgerald & Levine, 1992; Vallacher & Nowak, 1994). The "why" of our belief in the future prominence of dynamical systems modelling in developmental research has both evolutionary and pragmatic roots. First, it follows from the likely progression of scientific development as described (forecast?) by, for example, West (1985). Successful scientific disciplines proceed from description and static formulation to dynamic ones. For a developmental science, in particular, the appeal of such a progression is great and its logic defies serious protesting; one can only hope to accelerate the transition. Second, within the restricted scope of the current paradigms and Zeitgeist, greater and greater demands have been placed on all aspects of the methodological toolkit, including measurement, design, and modelling, by theoretical propositions requiring empirical test. Examples of why there is an increased demand for greater methodological power include conceptual formulations, such as *multidirectionality of change* and simultaneous *gains and losses* across the lifespan (Baltes, 1987). The accompanying theory-testing exigencies are not being met adequately by the traditional methods of developmental psychology and will not be in the future. From our perspective, abandoning the current methodological paradigms, as painful as it will be for some, is an inevitability. And even as history's odometer rolls up a new string of zeroes, there is reason to be optimistic because of the advances that are already in evidence.

The "how" of our belief in the promise of dynamical systems modelling flows from several developments of the past few decades. For example, even without the desired methodological "back-up" being readily available, systems thinkers have increasingly focused on developmental issues and problems (e.g., Ford, 1987; Ford & Lerner, 1992; Kelso, 1995; Thelen & Smith, 1994). Moreover, methodologists have become increasingly sophisticated in the quantification of change within the dynamic approach (Arminger, 1986; Boker & Nesselroade, 1999; Coleman, 1968; McArdle & Hamagami, in press; Tuma & Hannan, 1984) and the developments are filtering down to developmental researchers.

A key methodological point worth special mention has to do with the emergence of a greater appreciation for the distinction

[1] An anonymous reviewer suggested the phenomenon of transposition as studied by the gestaltists as an early illustration of this idea.

[2] In Hampson's work, for example, in terms of sheer magnitude of variability, differences among persons in abilities appear to be substantially greater than changes within persons over relatively short time periods. This may be a function, in part, of the nature of extant measurement instruments. Some earlier work involving measurement instruments constructed especially for many repeated testings of abilities (Moran & Mefferd, 1959) indicated greater similarity in amounts of the two kinds of variability. Nesselroade and Featherman (1991) reported similar amounts of intraindividual and interindividual variability in repeated measurements with depression scale items.

between a specific sequence and what might be called *temporal generality*. From the standpoint of establishing lawful relationships, knowing a likely ordering (e.g., X is followed by Y) is far more useful than knowing a particular sequence (Y at Time 2 follows X at Time 1) that may or may not be repeatable across Times 3 and 4. The difference is captured in figures that plot amounts of some attribute across age or time versus those that plot amounts of change in some attribute across lags. Dynamic models are pointedly aimed at representing such temporally general phenomena.

From the standpoint of measurement, research design, and data analysis considerations—the methodological triumvirate on which developmental science rests—these "why" and "how" considerations entail a number of important issues. We will examine some of them in more detail.

Measurement issues

Powerful developments in the modelling of behavioural phenomena can never leap very far ahead of the quality of the available measurement. The study of behavioural development is no exception. Whereas psychometricians have seemingly pushed the limits of classical test theory in the pursuit of studying development and other kinds of changes, sometimes with unsatisfactory results, some promising new developments in item response theory (IRT) remain to be explored and developed. Obviously, the "jury is still out" with regard to the generality of IRT models, but the critical need for more effective representations of process compels a thorough evaluation of their efficacy in multiple, diverse applications.

Contributions of item response theory to developmental research issues

Item response theory has helped to bring on several measurement advances pertinent to developmental study in the last two decades. The most common and most successful applications of IRT are in ability measurement, although many successful IRT applications in other areas, for example, personality (e.g., Reise, Widaman, & Pugh, 1993; Steinberg & Thissen, 1995) also exist. First, IRT provides increased precision in measuring abilities and other traits of individuals. Although it is true that IRT theta scores and raw scores are highly correlated (see e.g., Lawson, 1991) and that IRT and classical test theory are similar in many ways (see e.g., Mellenbergh, 1996), the enhanced precision of IRT lies in its interval-level measurement of persons and items, and sensitivity towards errors of measurement at extreme ends of the ability scale.

Second, because IRT allows one to estimate item difficulties and individuals' ability levels on a common scale, measurement processes can also be made very efficient by "tailoring" the set of items to the target individual's ability level, allowing for greater reliability with the use of fewer items. This *conjoint additivity* feature (Rasch, 1960) allows the researcher to control a test's developmental appropriateness for a given population of individuals. With IRT, models exist for dichotomous, polytomous, and continuous item response formats and thus can adequately represent many different kinds of developmental content areas.

Third, as is well known (e.g., Bereiter, 1963), representing change via raw difference scores can be psychometrically problematic. For example, change from different initial levels can have different meaning, as in the case in which a change from 1 to 2 may not mean the same as a change from 7 to 8. Several developments in IRT models have addressed the measurement of change in ways that are directly pertinent to the study of development. For example, The Partial Credit Model (Masters, 1982) is useful for items designed for estimating stage-related processes in a multiple-response format. Responses to B indicate more acquired knowledge than responses to A, but less than to C. The Saltus Model (Wilson, 1989) measures discontinuous stage changes in people. The impact of developmental stages on different item types elaborates the nature of the developmental change. The Multidimensional Rasch Model for Learning and Change (MRMLC; Embretson, 1991) estimates an initial trait level, and one or more abilities on separate dimensions after an intervention has been administered. The separate, additional dimensions indicate the degree of the person's modifiability, based on an interval-level scale and the features of the items encountered, and remedies the psychometric issues outlined by Bereiter (1963).

Fourth, in the classical test theory context, what to do about missing data is often problematic. Because IRT models use available data for a matrix of item responses for estimating the item difficulties and person abilities, an item not reached or an item not presented has an associated probability of correct response, given the ability level of the person. Computerised adaptive testing (Lord, 1980; Weiss, 1984) applies this feature by presenting the next best item to a respondent, given available responses to items in the test and the respondent's pattern of item responses so far. Hence, attribute levels can be efficiently estimated using the available responses.

Interfacing IRT with existing methods

With the measurement advances of IRT models have come their combination with powerful modelling and data-analytic methodologies to the further enhancement of both. For example, IRT has been joined with hierarchical linear modelling (Adams, Wilson, & Wu, 1997) as a multilevel approach for the discernment of item responses for the within-person model and the distribution of people for the between-person model in the context of educational progress assessments. IRT has also been combined with factor analysis (Bock, Gibbons, & Muraki, 1988; Muraki & Carlson, 1995) in a method called full-information factor analysis. With this method, linear combinations of several abilities predict item solution probabilities. Item responses, rather than total scores, are modelled for parameter estimates. IRT has also been teamed with latent class analysis (Rost, 1990) to categorise mixed populations into separate, qualitatively different latent classes based on patterns of item responses. Subgroups that use different processing strategies can be discriminated from each other by examining item context, or extensive modelling using other ability tests (see e.g., Schmidt McCollam, 1998).

Capitalising on IRT to measure processes

Decomposing cognitive processes into components represents an important approach in several areas, including the study of development. The work of Sternberg (1977) on analogies, for example, included creating subtask-level items of processes postulated to underlie the total task. More recently, several significant approaches have been developed to estimate cognitive-processing components and item features in IRT.

Fischer's (1973) Linear Logistic Latent Trait Model (LLTM), specifically incorporates an item's complexity features into item success prediction. Using stimulus features, the impact of the processes specified by a mathematical model are directly estimated. For example, a set of spatial visualisation items postulated to require image transformation can be modelled for varying degrees of rotation using LLTM. Furthermore, this model can be compared to a simple Rasch model to estimate the efficacy of the postulated processing requirements on performance. In the cognitive area, for example, examples of LLTM applications can be found in Embretson (1983, 1999).

Embretson (1995) combined the LLTM with the General Latent Trait Model (GLTM; Embretson, 1984) to estimate covert processes of working memory and general control in abstract reasoning items using the EM algorithm (Dempster, Laird, & Rubin, 1977). The GLTM's use of the EM algorithm estimates processing components without using subtask data. As the model uses both LLTM and GLTM, item features are modelled and component processes are modelled. With their combinations, the probability of component success depends on ability and item difficulty. More recent applications of this approach can be found in Embretson (1999).

Sheehan (1997) used a hierarchical method of regression to form clusters of items organised at different levels reflecting similar cognitive properties postulated to govern processing complexity. As in other Rasch models, successive levels of clusters are located on a common scale for item difficulty and ability. The meaning of the processing components is enhanced by examining item properties and features corresponding to a given level.

Design issues

As we noted earlier, designing data collection strategies to enhance empirical work within a living systems orientation brings one face-to-face with issues that remained somewhat obscured at earlier times in our history. Here, we will confine our remarks to a couple of illustrative issues that arise within the context of longitudinal work.

Longitudinal data have held an attraction for developmentalists for a long time and we are continually learning how to better exploit them. Wohlwill (1973), for example, closely examined the role of longitudinal data in developmental research. In general, research designs can still be evaluated effectively within the framework laid down by Campbell and Stanley (1963) and further refined and elaborated by Cook and Campbell (1979). However, some refinements have appeared that, on the surface, seem to threaten design validity but, at a deeper level, serve to enhance it. Other refinements are "demanded' by the focus on intra-individual variability inherent in a living systems orientation. With regard to the latter, the attendant assumptions of intra-individual variability patterning in rhythms and cycles, for instance, raises key questions regarding length and numbers of sampling intervals and other time-based concerns that have not seemed so critical in traditional longitudinal designs. Finding the correct answers is a major design concern (Nesselroade & Boker, 1994). Among these kinds of design concerns is the capture of intra-individual variability information by "bursts" of measurement.

Also assuming increased salience as repeated measurement designs proliferate is the matter of missing data. Increased sophistication in the way "missingness" is conceptualised and handled (e.g., Rubin, 1976) offers some comfort for the inevitable losses that are suffered when complex and prolonged sampling schemes are implanted. One of the more "positive" ways to view the issue of missingness is to deliberately incorporate it into one's design to increase efficiency.

Planned missingness

Planned missingness is by no means a new concept. Scaling studies involving lots of stimuli were designed around planned incomplete comparisons by judges (Torgerson, 1958). In developmental research, sequential models (Baltes, 1968; Bell, 1954; Schaie, 1965) made it possible to synthesise longitudinal curves without measuring all participants at all occasions of measurement. Such planned lacunae in research designs are now part of the engineering of data collection used in complicated structural equation models (McArdle & Hamagami, 1991).

Bursts of measurement

Getting a better fix on the behaviour of a system as reflected in intra-individual variability characteristics requires a different kind of research design, whether cross-sectional or longitudinal in its basic aspect.[3] To assess intra-individual variability at a given observational period requires multiple measurements, be they separated by a few moments or a few days. Elsewhere, a set of measurements designed to yield a single intra-individual variability score has been referred to as a "burst" (Nesselroade, 1991). Bursts of measurement can be incorporated into cross-sectional, longitudinal, or sequential designs in order to study intra-individual variability. Obviously, bursts of measurements increase the researcher burden in various ways. In addition to expense, for example, problems associated with measurement issues (e.g., testing effects) can be increased. Still, bursts of measurement are intrinsically necessary for some traditional approaches (e.g., testing-the-limits to assess learning potential) as well as newer ones. Dynamical systems modelling demands different data than did traditional longitudinal designs, however, so these newer design questions, such as: "Over how many measurements and at what interval should bursts be defined?" must be answered.

Modelling issues

As with design issues, there are many modelling issues that must be addressed in a discussion of dynamical systems representation. Two matters, in particular, are critical to furthering our ability to model developing systems. One is the representation of dynamics both in single and in coupled variables. The second is the capacity to represent "shocks" and their influence on a system. The importance of being able to model "shocks" or other inputs from outside the organism is difficult to overestimate. Developmentalists know that devel-

[3] An issue that has long been salient in developmental research and has become so in the context of living systems modeling has to do with the extent to which differences among entities and changes within entities represent the same phenomena and thus warrant making a few observations on many entities as a substitute for making many observations on a single entity to learn about the development or evolution of a system. The dangers of this kind of expedient substitution were pointed out decades ago by Bereiter (1963) in his discussion of dilemmas in the measurement of change. Resolving the issue well bears directly on the conduct and the promise of future developmental research (Nesselroade & Molenaar, 1999).

opment of the organism does not occur in a vacuum. The whole of contextualism has helped to shape our acceptance of the idea that the organism is continuously influenced by its surroundings; at many different levels. Crucial instances not only of having the necessary stimulus inputs but the importance of their timing have now been well established in the literature.

Dynamic factor model

Beginning with its applications to understand and model concepts such as differentiation and reintegration, the factor analytic model has planed an important role in developmental research (Reinert, 1970). At about the same time that Garrett (1946) and Burt (1954) were demonstrating the usefulness of factor analysis for modelling age-related interindividual differences in human abilities, Cattell, Cattell, and Rhymer (1947) illustrated its value for representing intra-individual variability phenomena by applying it to the single case measured over many occasions (P-technique factor analysis). Nearly forty years later, significant improvements in the factor model as a tool for modelling intra-individual variability (McArdle, 1982; Molenaar, 1985) by combining it with some of the logic of time-series analysis have helped to launch some novel and promising approaches to the study of individual exemplars of living systems (Nesselroade & Molenaar, 1999; Shifrin, Hooker, Wood, & Nesselroade, 1997; Wood & Brown, 1994).

Linear and nonlinear dynamical models

One of the key directions in which concern for modelling living systems has led social and behavioural scientists, including some developmentalists, is to the implementation of dynamical models, both linear and nonlinear (see e.g., Fitzgerald & Levine, 1992; Kelso, 1995; Molenaar, 1985; Thelen & Smith, 1994; Tuma & Hannan, 1984; Vallacher & Nowak, 1994). Precisely representing the relationships between the current state of an ensemble of variables and the subsequent state of those variables, a capacity richly exemplified by dynamical models when the ensemble behaves in an appropriately coherent way, is the great strength of dynamical models. The range of phenomena to which these models are being applied in psychology is impressive, given their relatively recent emergence there. As efforts succeed to widen the applicability of such models by finding better ways to estimate parameters accurately from relatively small numbers of observations (see e.g., Boker & Nesselroade, 1999), the benefits become ever more within reach of developmental researchers.

Conclusions

The ending of one millennium and the beginning of another is an opportune moment to take stock of where developmental researchers are and where we might be going in the quest to understand developmental process. We have identified some of the key, attendant methodological issues and suggested how progress in resolving them might be made. Our perspectives are based in part on observation and in part on speculation; the latter seasoned with more than a little hope. Hope, by definition, is future-oriented, so it seems appropriate to use it as a touchstone for a few concluding comments.

For the sake of developmental science, we hope that some of the directions of future growth that have begun to emerge in the past decade or so proceed at an accelerating pace. For example, the realisation that the human organism is not an ensemble of more or less constant scores but rather, an ensemble of interrelated variables has helped to make researchers a little more sensitive to the need to include conceptions of inherent change and dynamics to their particular domains of content. This need also extends beyond the modelling and analysis efforts to include measurement and design issues.

Developmental science can ill afford to continue with "business as usual" when so many signs point toward both the need for advanced conceptions and the possibilities of their being within the methodological reach of those who dare to lean over the edge and stretch a bit. Building more sensitive measurement devices, designing more change-oriented studies, and employing more dynamical models is possible—and promises to be worth the investment.

In collaboration with much needed improvements in theoretical conception, we believe that it will be through concerted attention to measurement, design, and analysis issues that significant progress in the modelling of process will occur. As we have tried to point out in this article, we believe that the methodological tools are available to take the study of process to another level. If the current generations of developmentalists do not assume the responsibility for doing so, it is not likely to happen for a very long time. If developmentalists do take on this challenge, the next millennium will be one of dramatic breakthroughs in our understanding of behavioural development. We hope the challenge will be accepted eagerly.

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References

Adams, R.J., Wilson, M., & Wu, M. (1997). Multilevel item response models: An approach to errors in variable regression. *Journal of Educational and Behavioral Statistics, 22*, 47–76.

Arminger, G. (1986). Linear stochastic differential equation models for panel data with unobserved variables. In N. Tuma (Ed.), *Sociological methodology 1986* (pp. 187–212). San Francisco: Jossey-Bass.

Baltes, P.B. (1968). Longitudinal and cross-sectional sequences in the study of age and generating effects. *Human Development, 11*, 145–171.

Baltes, P.B. (1987). Theoretical propositions of life-span developmental psychology: On the dynamics between growth and decline. *Developmental Psychology, 23*, 611–626.

Baltes, P.B. (1997). On the incomplete architecture of human ontogeny: Selection, optimization, and compensation as foundation of developmental theory. *The American Psychologist, 52*, 366–380.

Baltes, P.B., Reese, H.W., & Nesselroade, J.R. (1977). *Life-span developmental psychology: Introduction to research methods.* Monterrey, CA: Brooks/Cole.

Bell, R. (1954). An experimental test of the accelerated longitudinal approach. *Child Development*, 381–386.

Bereiter, C. (1963). Some persisting dilemmas in the measurement of change. In C.W. Harris (Ed.), *Problems in measuring change.* Madison, WI: University of Wisconsin Press.

Bergman, L.R. (1998) A pattern-oriented approach to studying individual development: Snapshots and processes. In R.B. Cairns & L.R. Bergman (Eds.), *Methods and models for studying the individual* (pp. 83–122). Thousand Oaks, CA: Sage.

Bergman, L.R., & El-Kouri, B.M. (1999). Studying individual patterns of development using i-states as objects analysis (ISOA). *Biometrical Journal, 41*, 753–770.

Bock, R.D., Gibbons, R., & Muraki, E.J. (1988). Full information item factor analysis. *Applied Psychological Measurement, 12*, 261–280.

Boker, S.M., & Nesselroade, J.R. (1999). *A method for modeling the intrinsic dynamics of intraindividual variability: Recovering the parameters of simulated oscillators in multi-wave data.* Unpublished manuscript, Department of Psychology, University of Notre Dame, IN.

Burt, C. (1954). The differentiation of intellectual abilities. *British Journal of Educational Psychology, 24*, 76–90.

Cairns, R.B., Bergman, L.R., & Kagan, J. (Eds.) (1998). *Methods and models for studying the individual.* Thousand Oaks, CA: Sage.

Campbell, D.T., & Stanley, J.C. (1963). Experimental and quasi-experimental designs for research on teaching. In N.L. Gage (Ed.), *Handbook of research on teaching.* Chicago: Rand McNally.

Cattell, R.B. (1963). The interaction of hereditary and environmental influences. *The British Journal of Statistical Psychology, 16,* 191–210.

Cattell, R.B., Cattell, A.K.S., & Rhymer, R.M. (1947). P-technique demonstrated in determining psychophysical source traits in a normal individual. *Psychometrika, 12,* 267–288.

Coleman, J.S. (1968). The mathematical study of change. In J.H.M. Blaylock & A. Blaylock (Eds.) *Methodology in social research* (pp. 428–478). New York: McGraw-Hill.

Collins, L., & Sayer, A. (Eds.) (in press). *Methods for the analysis of change.* Washsington, DC: American Psychological Association.

Collins, L.M., & Horn, J.L. (Eds.) (1991) *Best methods for the analysis of change.* Washington DC: American Psychological Association.

Cook, T.D., & Campbell, D.T. (Eds.). (1979). *Quasi-experimentation: Design and analysis for field settings.* Chicago: Rand McNally.

Dempster, A.P., Laird, N., & Rubin, D.B. (1977). Maximum likelihood estimation from incomplete data via the em algorithm (with discussion). *Journal of the Royal Statistical Society, Series B, 39,* 1–38.

Embretson, S. (1995). Working memory capacity versus general control processes in intelligence. *Intelligence, 20,* 169–189.

Embretson, S.E. (1983). Construct validity: construct representation versus nomoethic span. *Psychological Bulletin, 93,* 179–197.

Embretson, S.E. (1984). A general multicomponent latent trait model for response processes. *Psychometrika, 49,* 175–186.

Embretson, S.E. (1991). A multidimensional latent trait model for measuring learning and change. *Psychometrika, 56,* 495–516.

Embretson, S.E. (1999). A cognitive design system approach to generating valid tests: Application to abstract reasoning. *Psychological Methods, 3,* 380–396.

Fischer, G.H. (1973). Linear logistic test model as an instrument in educational research. *Acta Psychologica, 37,* 359–374.

Fitzgerald, H.E., & Levine, R.L. (Eds.) (1992). *Analysis of dynamic psychological systems.* New York: Plenum.

Ford, D.H. (1987). *Humans as self-constructing living systems.* Hillsdale, NJ: Erlbaum.

Ford, D.H., & Lerner, R.M. (1992). *Developmental systems theory: An integrative approach.* Newbury Park, CA: Sage.

Garrett, H.E. (1946). A developmental theory of intelligence. *The American Psychologist, 1,* 372–378.

Hampson, E. (1990). Variations in sex-related cognitive abilities across the menstrual cycle. *Brain and Cognition, 14,* 26–43.

Holling, C.S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics, 4,* 1–23.

Horn, J.L. (1972). State, trait, and change dimensions of intelligence. *The British Journal of Educational Psychology, 42,* 159–185.

Kelso, J.A.S. (1995). *Dynamic patterns: The self-organization of brain and behavior.* Cambridge, MA: MIT Press.

Lawson, S. (1991). One parameter latent trait measurement: Do the results justify the effort? In B. Thompson (Ed.), *Advances in educational research: Substantive findings, methodological developments* (Vol. 1, pp. 159–168). Greenwich, CT: JAI.

Lord, F.M. (1980). *Applications of item response theory to practical testing problems.* Hillsdale, NJ: Erlbaum.

Magnusson, D. (1995). Individual development: A holistic, integrated model. In P. Moen. G.H. Elder, Jr., & Lüscher (Eds.), *Examining lives in context: Perspectives on the ecology of human development.* Washington, DC: American Psychological Association.

Masters, G.N. (1982). A rasch model for partial credit scoring. *Psychometrika, 47,* 149–174.

McArdle, J.J. (1982). *Structural equation modeling of an individual system: Preliminary results from "A case study in episodic alcoholism".* Unpublished manuscript, Department of Psychology, University of Denver, Co.

McArdle, J.J., & Hamagami, F. (1991). Modeling incomplete longitudinal data using latent growth structural equation models. In L.M. Collins & J.L. Horn (Eds.), *Best methods for the analysis of change: Recent advances, unanswered questions, future directions* (pp. 276–304). Washington, DC: American Psychological Association.

McArdle, J.J., & Hamagami, F. (in press). Linear dynamic analyses of incomplete longitudinal data. In L. Collins & A. Sayer (Eds.), *Methods for the analysis of change.* Washington, DC: American Psychological Association.

McCrae, R.R., & Costa, P.T. (1996). Toward a new generation of personality theories: Theoretical contexts for the five-factor model. In J.S. Wiggins (Ed.), *The five-factor model of personality: Theoretical perspectives* (pp. 51–87). New York: Guilford Press.

Mellenbergh, G.J. (1996). Measurement precision in test score and item response models. *Psychological Methods, 1,* 293–299.

Mischel, W. (1968). *Personality and assessment.* New York: Wiley.

Molenaar, P.C.M. (1985). A dynamic factor model for the analysis of multivariate time series. *Psychometrika, 50,* 181–202.

Moran, L.J., & Mefferd, R.B. (1959). Repetitive psychometric measures. *Psychological Reports, 5,* 269–275.

Muraki, E., & Carlson, J.E. (1995). Full-information factor analysis for polytomous item responses. *Applied Psychological Measurement, 19,* 73–90.

Nesselroade, J.R. (1991). The warp and woof of the developmental fabric. In R. Downs, L. Liben, & D. Palarmo (Eds.), *Visions of development, the environment, and aesthetics: The legacy of Joachim F. Wohlwill.* Hillsdale, NJ: Erlbaum.

Nesslelroade, J.R., & Boker, S.M. (1994). Assessing constancy and change. In T. Heatherton & J. Weinberger (Eds.), *Can personality change?* Washington, DC: American Psychological Association.

Nesselroade, J.R., & Featherman, D.L. (1991). Intraindividual variability in older adults' depression scores: Some implications for developmental theory and longitudinal research. In D. Magnusson, L.R. Bergman, G. Rudinger, & B. Törstad (Eds.), *Problems and methods in longitudinal research: Stability and change* (pp. 47–66). Cambridge, UK: Cambridge University Press.

Nesselroade, J.R., & Featherman, D.L. (1997). Establishing a reference frame against which to chart age-related change. In M.A. Hardy (Ed.), *Studying aging and social change: Conceptual and methodological issues* (pp. 191–205). Thousand Oakes, CA: Sage.

Nesselroade, J.R., & Ford, D.H. (1987). Methodological considerations in modeling living systems. In M.E. Ford & D.H. Ford (Eds.), *Humans as self-constructing living systems: Putting the framework to work* (pp. 47–79). Hillsdale, NJ: Erlbaum.

Nesselroade, J.R., & Molenaar, P.C.M. (1999). Pooling lagged covariance structures based on short, multivariate time-series for dynamic factor analysis. In R.H. Hoyle (Ed.), *Statistical strategies for small sample research.* Newbury Park, CA: Sage.

Rasch, G. (1960). *Probabilistic models for some intelligence and attainment tests.* Copenhagen: Danmarks Paedagogiske Institut.

Reinert, G. (1970). Comparative factor analytic studies of intelligence throughout the human life span. In L.R. Goulet & P.B. Baltes (Eds.), *Life-span developmental psychology: Research and theory* (pp. 467–484). New York: Academic Press.

Reise, S.P., Widaman, K.F., & Pugh, P.H. (1993). Confirmatory factor analysis and item response theory: Two approaches for exploring measurement invariance. *Psychological Bulletin, 114,* 552–566.

Rost, J. (1990). Rasch models in latent classes: An integration of two approaches to item analysis. *Applied Psychological Measurement, 14,* 271–282.

Rubin, D. (1976). Inference and missing data. *Biometrika, 63,* 581–592.

Schaie, K.W. (1965). A general model for the study of developmental problems. *Psychological Bulletin, 64* 92–107.

Schmidt McCollam, K.M. (1998). Latent trait and latent class models. In G.M. Marcoulides (Ed.), *Modern methods for business research* (pp. 23–46). Mahwah, NJ: Erlbaum.

Sheehan, K.M. (1997). A tree-based approach to proficiency scaling and diagnostic assessment. *Journal of Educational Measurement, 34,* 333–354.

Shifrin, K., Hooker, K.A., Wood, P.K., & Nesselroade, J.R. (1997). The structure and variation in mood in individuals with Parkinson's disease: A dynamic factor analysis. *Psychology and Aging, 12,* 328–229.

Shoda, Y., Mischel, W., & Wright, J.C. (1993). The role of situational demands and cognitive competencies in behavior organization and personality coherence. *Journal of Personality and Social Psychology, 65,* 1023–1035.

Steinberg, L., & Thissen, D. (1995). Item response theory in personality research. In P.E. Shrout & S.T. Riske (Eds.), *Personality research, methods and theory: A festschrift honoring Donald W. Fiske* (pp. 161–181). Mahwah, NJ: Erlbaum.

Sternberg, R.J. (1977). *Intelligence, information-processing, and analogical reasoning: The componential analysis of human abilities.* Hillsdale, NJ: Erlbaum.

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

Torgerson, W.J. (1958). *Theory and methods of scaling.* New York: Wiley.

Tuma, N.B., & Hannan, M.T. (1984). *Social dynamics: Models and methods.* New York: Academic Press.

Vallacher, R.R., & Nowak, A. (Eds.) (1994). *Dynamical systems in social psychology.* San Diego, CA: Academic Press.

van der Maas, H.L., & Molenaar, P.C.M. (1992). Stagewise cognitive development: An application of catastrophe theory. *Psychological Review, 99,* 395–417.

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

Weiss, D.J. (1984). Application of computerized adaptive testing to educational problems. *Journal of Educational Measurement, 21,* 361–376.

West, B. (1985). *An essay on the importance of being nonlinear.* Berlin: Springer.

Wilson, M. (1989). Saltus: A psychometric model of discontinuity in cognitive development. *Psychological Bulletin, 105,* 276–289.

Wohlwill, J.F. (1973). *The study of behavioral development.* New York: Academic Press.

Wood, P., & Brown, D. (1994). The study of intraindividual differences by means of dynamic factor models: Rationale, implementation, and interpretation. *Psychological Bulletin, 116,* 166–186.