Nonlinear Models of Development:
An Example from the Socialization of Competence

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Abstract

While the use of linear models is common, many of the important phenomena of developmental psychology are probably nonlinear in nature, since this is a characteristic of behavioral systems with a strong maturational component. Using the socialization of competence as an example, this paper describes the development of a three dimensional topological model of outcomes that generates a number of non-linear relationships between child competence and parental warmth and control. In an initial test of the model, data were collected from 30 families using home observations, observer ratings, and self reports to assess parenting. Children's competence in preschool was assessed by Baumrind's Preschool Behavior Q-Sort and the Peabody Picture Vocabulary Test. Nonlinear relationships of the type predicted were found across methods, and accounted for substantial portions of the variance in the competence measures. These results suggest that the construction of nonlinear models is both practical and important.

The use of linear models is common in psychology. Such models are mathematically easier to conceptualize and use than nonlinear models, they seem appropriate to a wide range of data, and they frequently lend themselves to straightforward interpretations (e.g., the more, the better). In addition, linear models can be generalized to multivariate problems, i.e., from two or three dimensions to *n* dimensions.

In spite of the prevalence of linear models, there is good reason to think that many of the important phenomena of developmental psychology are nonlinear in nature. Physiological and behavioral systems with a strong maturational component, for example, typically exhibit threshold effects. While extremely low levels of crucial environmental variables result in suboptimal development, after some minimum environmental threshold is passed which allows the system to develop normally, additional increases in environmental levels have little, if any, further impact. This pattern is frequently seen in physical, cognitive, and language development, and Bowlby (1982) gives many examples of systems which develop stably across a wide range of environments. Graphically, threshold effects are represented by nonlinear functions, e.g., as sigmoidal curves, in which a rapid rise is followed by a plateau.

In spite of the pervasiveness and complexity of nonlinear phenomena, nonlinear models have remained relatively simple. Most overtly nonlinear models are two dimensional; examples are inverted-U functions and memory decay curves. Multivariate nonlinear situations are often presented in ways that make the underlying nonlinear functions less explicit, e.g., as interaction effects in ANOVAs (where the emphasis is on differential effects across categories) or as moderating variables in descriptions of main effects. While nominal data require such treatment, continuous nonlinear data are sometimes also broken into categories for the sake of interpretability. Thus Baumrind (1971), for example, divided her sample of parents into types or patterns based on different levels of control and warmth, and then described the relationship of each type to child competence. As she makes clear, however, both warmth and control had nonlinear (inverted-U) relationships with competence when considered individually.

Although categorical approaches are intuitively appealing and often useful, there is much to be gained by developing multivariate models that are explicitly nonlinear in nature. Since such models probably reflect more closely the actual nature of developmental phenomena, they should be more satisfactory in the long run. In addition, the process of making explicit models is a powerful heuristic, pointing out current theoretical shortcomings as well as suggesting new relationships between variables and new research directions. Moreover, when these descriptive models incorporate antecedent and outcome variables, they serve as necessary precursors to building causal (or process) models, since they define the phenomena to be explained.

Nevertheless, there are difficulties to be encountered in the use of nonlinear models. How are they to be constructed and evaluated? How well can they be interpreted? Are they powerful enough to warrant using?

We will discuss both the advantages and difficulties of nonlinear modeling more fully in the context of a model that I have used in studying the relationships between parental warmth and control and children's competence. As will be seen, this three dimensional topological model is capable of generating mathematical relationships with competence given occurring values for parental warmth and control. Before describing the model and its development, however, it will be useful to briefly discuss the underlying constructs.

Competence in Young Children. In ordinary usage, competence refers to the ability to perform adequately in a given situation (Webster and McKechnie, 1978). There is substantial agreement in the research literature that for children this ability is generally manifested as goal-oriented, planful behavior (Baumrind, 1971; Block and Block, 1980), and includes in social situations the skills to initiate and sustain nondisruptive social interactions and to appropriately modulate affect (Ainsworth and Bell, 1974; Baumrind, 1971; Lamb, Easterbrooks, and Holden, 1980; Sroufe, Motti, Lawroski, and LaFreniere, 1984). Whereas the distinction between social and purely task-oriented activities and competence is clear in theory, in practice task-oriented activities frequently involve social components (Matas, Arend, and Sroufe, 1978).

Parental Warmth and Control. Warmth, defined as liking or affection, and control, or the assertion of power to achieve compliance, have been identified in previous research as underlying dimensions of parenting (see Maccoby and Martin, 1983, and Martin, 1975, for reviews). Both have been thought to be important determinants of child outcomes.

Responsiveness (i.e., adult sensitivity to child cues) has also been identified as an important component of parenting (e.g., by Ainsworth, Blehar, Waters, and Wall, 1978). In social contexts, this is marked by social responses to children's social initiations. In agonistic contexts, it is marked by parents' willingness to solicit, accept, and be influenced by the child's point of view. (Responsiveness so defined differentiates authoritative and authoritarian parenting, for example.) Because of obvious conceptual and behavioral affinities, responsiveness has often been considered (at least implicitly) as an aspect of overall parental warmth.

These characteristics of parenting have been thought to affect the development of competent behavior by several mechanisms. Willingness to explore and engage both the social and non-social environment is strongly affected during infancy and early childhood by quality of attachment, which in turn is influenced by parental responsiveness (Ainsworth et al., 1978; Arend, Gove, and Sroufe, 1979). In middle and late childhood, access to the wider environment may be either actively encouraged or restricted by parents (Block, 1983). In all cases, experience has multiple implications for competence, from the acquisition of specific skills and knowledge, to the development of both general cognitive schemata and representational models of the self, the world, and one's abilities in it (Bowlby, 1982; Piaget, 1983). Parent-child interactions also undoubtedly contribute directly to the formation of these representational models (e.g., to self concept and self efficacy). Thus parental social responsiveness may constitute a child's first and most primary experience as an effective social agent, while parental overcontrol and undercontrol may contribute to learned helplessness, as Baumrind (1977) speculates.

A topological model for the socialization of competence. As the foregoing discussion has implied, the first step in constructing the model presented here was

the selection of an outcome dimension (children's competence) and other dimensions (parental warmth and control) thought to be causally related to it. This is not a *sine qua non*; one could, for example, use a proxy variable such as SES as a basic dimension. However, since models summarize the relationships observed or thought to exist between the factors incorporated in them, causally related variables are often the most interesting to employ.

Another theoretical consideration was responsible for the basic nonlinear nature of the model. Since competence meets the criteria set out by Bowlby (1982) for environmentally stable behavioral systems (i.e., regularity of development across a wide range of environmental conditions and some obviously adaptive evolutionary function), the model incorporates zones of sharp transition. Thus the model extends two dimensional sigmoidal curves to a three dimensional surface.

Empirical findings, noted below, also shaped the model, which is presented in Figure 1. The model is meant to be read like a topological map, i.e., the third

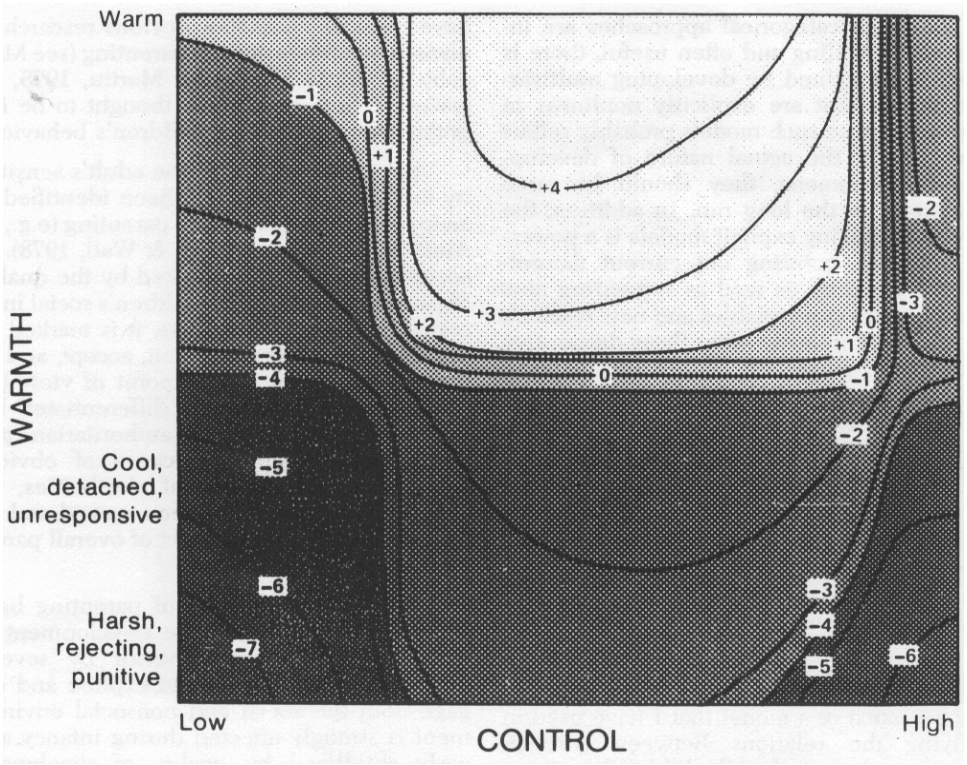

Figure 1. A topological model of the relations between parental warmth and control and child competence.

dimension, competence, is indicated by contour lines (numbered somewhat arbitrarily, with negative values indicating deficits). Zones of rapid transition are indicated schematically by areas A, B, and C in Figure 2. For example, moving along the Warmth axis, C in Figure 2 represents an area above which warmth and responsiveness are considered to be sufficient for the development of competence. Below it, warmth is insufficient. Likewise, moving along the control axis, A represents an analogous boundary. The decline at very high levels of control reflects the findings of Baumrind (1971). This decline occurs later at high levels of responsiveness and earlier at lower levels; thus zone B is not symmetrical with respect to zone A.

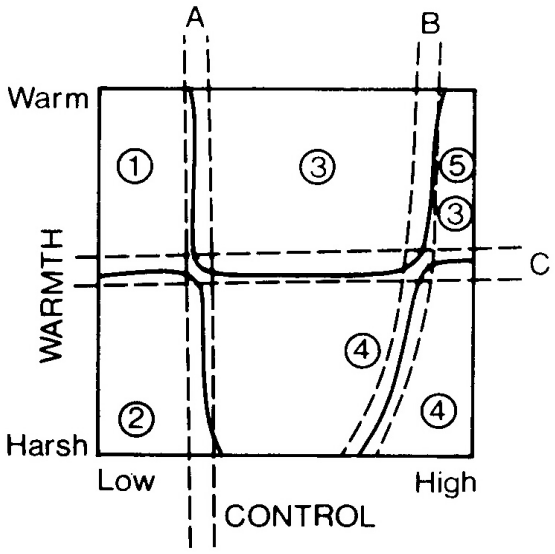

Figure 2. Schematic of Fig. 1, indicating zones of transition (A, B, C) and areas corresponding to types of parenting (1 = permissive, 2 = abusive, 3 = authoritative, 4 and 5 = authoritarian.

Areas on the topological model correspond to various types of parenting. Area 1, for instance, corresponds to Baumrind's category Permissive; area 2, to abusive parents; area 3 to Authoritative parenting; area 4 to Authoritarian parenting (as encountered in a white, North American context), and area 5, to Authoritarian parenting occurring as a social norm accompanied by parental warmth (Baumrind, 1971, 1973).

Slices of the solid shown in Figure 1 represent two-dimensional relations between competence and warmth or control, with different slices representing different relationships between the two parenting factors. For instance, if warmth and control are uncorrelated, then the relationship between warmth and competence is predicted by a slice through the model parallel to the warmth axis, and control and competence, by a slice parallel to the control axis. The x and y intercepts would be at the sample means of control and warmth, respectively. As control and warmth are found to be correlated (as they typically are in North American samples), the two

slices cease to be orthogonal with respect to one another. Their respective slopes and intercepts are then given by the regressions of *x* on *y* and *y* on *x*. At correlations of plus or minus 1, the two lines merge.

Thus, given any occurring values for warmth and control, the model generates functions relating each to children's competence. Note that these functions are not necessarily identical. For example, in a sample of parents who are relatively warm and controlling (Authoritative), and with low or moderate degrees of negative correlation between these two parenting factors, the model predicts an inverted-U relationship between control and competence, and a sigmoidal relationship between warmth and competence.

Testing the model

In a preliminary test of this nonlinear model, family interactions were assessed in 30 families, using home observations, observer ratings, and parents' self reports. These methods were selected to reflect the considerations discussed earlier. Thus the use of home observations allowed lag analyses of parents' responsiveness in both social and agonistic contexts, while self reports and observer ratings tapped dimensions of liking and warmth, as well as control.

Competence was assessed by having each child's preschool or daycare teacher complete Baumrind's Preschool Behavior Q-Sort, and by administering the Peabody Picture Vocabulary Test to each child. The Preschool Behavior Q-Sort was used because it samples the broad aspects of competent functioning outlined earlier. The Peabody was chosen as a measure of verbal competence and also because scores on such a standardized test are thought to partly reflect the ability of the child to perform in a structured and mildly stressful situation.

Polynomial regression equations were fit to the data in order to test for the predicted nonlinear relationships.

Method

Subjects

Thirty-five two-parent families with a preschool-aged child volunteered for the study in response to letters distributed through daycare centers and preschools in the

metropolitan area. Among the 30 families who completed the study, the average age of the 19 girls and 11 boys was 4.3 years (range, 3.0 to 5.8); 21 had at least one sibling, usually younger. Fathers' mean age was 34; mothers, 32 (range for both, 24 to 45). Mothers reported an average of 14 years of school, while fathers reported 16 (range for both, 9 to 21). Mean family income was slightly above the national average. The Duncan Socio-Economic Index ranged from 33 to 92, with a mean of 67.

Instruments and Procedures

Family interactions were assessed by three methods: home observations, observer ratings, and parents' self reports. Competence was assessed by teachers' ratings. The instruments used in each method and the variables derived from them are summarized in Table 1. As this table indicates, major constructs (warmth, control and competence) were assessed across methods.

Each family was seen four times. Parents' Q-Sorts were dropped off and picked up on the first two visits. Home observations comprised the third visit, while the Peabody Picture Vocabulary Test was administered during the fourth.

Home observations lasted approximately three hours, from suppertime until the child's bedtime. Initiator and target individuals as well as behaviors were recorded on a small computerized encoder. A focal-individual sampling strategy was used, with 10-minute sessions alternating between the child and each parent. An average of 847 events were recorded for each family (range, 605 to 1,228), over a mean of 128 minutes of actual sampling time (range, 83 to 181 minutes).

The intention of the coding scheme was to provide a comprehensive running record of family interactions. Activities (e.g., "watches TV", "reads") were coded, along with social initiations (e.g., "non-verbal bid for attention or physical contact", "speaks") and social responses (e.g., "hugs, holds", "ignores, no response"). Categories for coding agonistic exchanges (e.g., "hits", "threat gesture") were adapted from Strayer and Strayer (1976). Affective categories (e.g., "cries"; "anger voice, yells") were also included.

Measures of responsiveness and firmness for each parent were derived from lag analyses.

Table 1. *Methods, Instruments, and Variables for Family and Classroom Measures*

Method	Instrument	Variables	Comments
Family measures:			
Home observations	Real-time coding using focal-individual sampling	*Warmth:* Father Responsive Mother Responsive *Control:* Father Firm Mother Firm	Lag analyses; responses to child social initiations; responses following child noncompliance
Observer ratings	Parent-rating scales (Baumrind, 1970a, 1970b)	*Warmth:* Warm Responsive *Control:* Firm Directive	Parents rated jointly; variables derived from Baumrind, 1971
Self-report	Child-rearing practices Q sort (Block, 1965)	*Warmth:* Father Warm Mother Warm *Control:* Father Strict Mother Strict	Items for variables assembled rationally and tested empirically; item total *r*'s > .40
Competence:			
Teacher ratings	Preschool behavior Q sort (Baumrind, 1968)	Purposive (vs. aimless) Achievement oriented Friendly (vs. hostile to peers) Cooperative (vs. resistive with adults)	First four variables derived from Baumrind, 1971
		Ego Strength Peer Competence	From Waters, Wippman, and Sroufe, 1979
		Correlation to criterion sort	The criterion sort represents an ideally competent preschooler
Standardized test	Peabody Picture Vocabulary Test	Peabody Vocabulary score	

Three reliability sessions totaling 300 minutes of observation time were conducted by two observers. Percent agreement and Kappa were calculated by

comparing categories coded at each second in the two records, thus placing a premium on inter-rater timing as well as agreement. Under these stringent conditions, agreements divided by agreements plus disagreements equaled 79% (κ = .72).

Following the home observation session, the observer completed 46 Parent Rating Scales (Baumrind, 1970a, 1970b), rating both parents jointly (inter-rater correlation = .88). These scales were aggregated into four variables, following Baumrind (1971): Firm (e.g., "Willingly exercises power to obtain obedience"), Directive (e.g., "Regimen set for child"), Warm (e.g., "Remains open and accessible"), and Responsive[1] (e.g., "Has empathic understanding of child", "Encourages verbal give and take"). Scores for these four variables were expressed as a percentage of the total possible score.

Both mothers and fathers completed the Child Rearing Practices Q-Sort (Block, 1965), a 91-item set distributed across 7 categories ranging from "least descriptive" to "most descriptive" of their own parenting practices. Since factors reported by Block for families with older children had low inter-item correlations in this sample, two new scales for each parent were assembled rationally and tested empirically. The two scales Mother Strict and Father Strict contain items such as "I have strict, well-established rules for my child", while Mother Warm and Father Warm contain items such as "I express affection by hugging, kissing, and holding my child". Item-total correlation were .40 or better; Cronbach alphas ranged from .74 (Father Warm) to .78 (Father Strict). Scores on these self report variables were also expressed as a percentage of the total possible.

Competence was assessed by having each child's preschool or daycare teacher complete the Preschool Behavior Q-Sort (Baumrind, 1968), a 72-item set distributed across 9 categories, from "extremely characteristic" to "extremely uncharacteristic" of the child. For five cases this measure was completed individually by two teachers who knew the target child well. Their average correlation (.69) was almost identical with the reliability reported by Baumrind (1971).

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[1] Baumrind called this scale "Encourages Independence and Individuality".

Seven variables were derived from the Q-Sort, six of them indexing competence in specific areas. These were Friendly (vs. hostile to peers), Cooperative (vs. resistive with adults), Purposive (vs. aimless), Achievement Oriented (all from Baumrind, 1971), Peer Competence, and Ego Strength (both from Waters, Wippman, and Sroufe, 1979). Finally, a criterion Q-sort for competence was developed by having four child psychologists complete the sort for an ideally competent preschooler (based on their own understanding of that construct). The teachers' Q-Sort was correlated with this criterion as a measure of the child's overall competence.

As mentioned earlier, the Peabody Picture Vocabulary Test was administered to children during the fourth home visit.

Results

Family measures

On a descriptive level, parents in this sample were warm and responsive and moderately controlling, as shown in Table 2. While observed rates of parental firmness following noncompliance seem low, rates of initial child compliance were fairly high (fathers averaged 50.2%, mothers, 56.9%).

Table 2. *Mean Scores on Family Measures*

Variables and Methods	M	SD
WARMTH:		
Home observation:		
Father Responsive	8.5	8.6
Mother Responsive	8.7	6.6
Observer ratings:		
Warm	63.9	13.0
Responsive	69.1	10.7
Self-report:		
Father Warm	77.4	13.6
Mother Warm	76.7	12.8

(Table continues)

Variables and Methods	M	SD
CONTROL:		
Home observation:		
Father Firm	18.4	16.6
Mother Firm	22.8	18.9
Observer ratings:		
Firm	60.1	14.7
Directive	63.3	10.4
Self-report:		
Father Strict	48.3	15.8
Mother Strict	44.9	17.4

NOTE. The home observation variables represent percent probabilities derived from lag analyses. Thus the value for Father Responsive indicates a mean of 8.5% "ignores" following a child social initiation (values were reflected for subsequent analyses, in keeping with the variable name), while Father Firm indicates a mean of 18.4% reiteration of enforcement of a directive following child noncompliance. Values for self-report and observer rating variables are a percent of points possible on each scale.

As Table 3 indicates, observer rating and self report measures of warmth and control were, as anticipated, negatively correlated, although observation measures of firmness, in contrast, showed few significant correlations.

Competence

Since some of the competence variables were highly intercorrelated (see Table 4), the seven Q-sort measures of competence (Table 1) were grouped on the basis of a cluster analysis and aggregated using *z*-scores. As illustrated in Figure 3, the cluster analysis yielded two groups, a structure later confirmed by a principal components factor analysis with varimax rotation. The first group, General

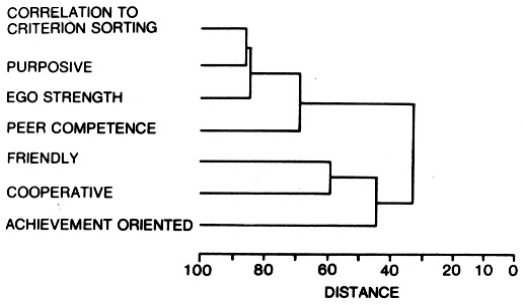

Figure 3. Cluster analysis (complete linkage) for the Q sort measures of competence.

Table 3. *Correlations among Family Interaction Variables*

Variables	2	3	4	5	6	7	8	9	10	11	12
1. Father Responsive (o)	.32*	.64****	.51***	.44**	.42**	.39**	NS	-.47***	NS	-.21	-.40**
2. Mother Responsive (o)		NS	NS	NS	.27	.42**	NS	-.23	NS	NS	NS
3. Warm (r)			.80****	.60****	.28	NS	NS	-.60****	-.20	-.36**	-.41**
4. Responsive (r)				.60****	.29	NS	NS	-.42**	NS	-.54***	-.49***
5. Father Warm (s)					.45**	NS	NS	-.59****	NS	-.71****	-.44**
6. Mother Warm (s)						NS	.30	-.51***	NS	-.40**	-.45**
7. Father Firm (o)							NS	NS	NS	NS	NS
8. Mother Firm (o)								-.21	NS	NS	-.26
9. Firm (r)									.49***	.22	.56***
10. Directive (r)										NS	.31*
11. Father Strict (s)											.35*
12. Mother Strict (s)											–

NOTE. $N = 30$. Correlations less than .20 are not tabled; NS = not significant.

(o) = home observation variable;

(r) = observer-rating variable (both parents rated jointly);

(s) = self-report variable.

* $p < .10$.

** $p < .05$.

*** $p < .01$.

**** $p < .001$.

Table 4. *Correlations among Measures of Competence*

Variables	2	3	4	5	6	7	8
1. Correlation to criterion sort	.86****	.85****	.73****	.46***	.43**	.62****	.37**
2. Purposive (vs. aimless)		.85****	.79****	N.S.	N.S.	.47***	.27
3. Ego Strength			.55***	.28	.41**	.70****	.31*
4. Peer Competence				N.S.	N.S.	.28	.34*
5. Friendly (vs. hostile to peers)					.59****	.32*	.22
6. Cooperative (vs. resistive with adults)						.60****	.31
7. Achievement Oriented							.36**
8. Peabody Vocabulary Score							—

NOTE. Correlations less than .20 are not tabled; N.S. = not significant. Variables 2, 5, 6, and 7 are from Baumrind (1971); variables 3 and 4 are from Waters *et al.* (1979).

* $p < .10$

** $p < .05$.

*** $p < .01$.

**** $p < .001$.

Competence, contained the correlation to the criterion sorting, Baumrind's scale Purposive, and the scales developed by Waters *et al.*, Ego Strength and Peer Competence. The second group, Cooperative-Task Oriented, contained Baumrind's scales Friendly, Cooperative, and Achievement Oriented.

The final measures of competence (i.e., the two aggregates and Peabody Picture Vocabulary scores) showed moderate convergence. General Competence and Cooperative-Task Oriented were significantly correlated with each other (r = .42) and with PPVT scores (r = .36 for each).

Testing the model: relationships between family measures and competence

Given the mean levels of warmth and control observed in this sample and the moderate negative correlations between them, the topological model presented in Figure 1 calls for sigmoidal relationships between warmth and competence and inverted-U relationships between control and competence. To test for these nonlinear relationships, polynomial functions were used to regress the family variables on the competence measures.

As predicted, sigmoidal relationships between warmth and General Competence emerged consistently across methods (see Table 5 and Figure 4, which illustrates a representative third degree polynomial function with General Competence), while inverted-U functions emerged for control variables across measures of competence (Table 5 and Figure 5, which illustrates a second degree polynomial function, and Figure 6, which illustrates a fourth degree variant of an inverted-U function).

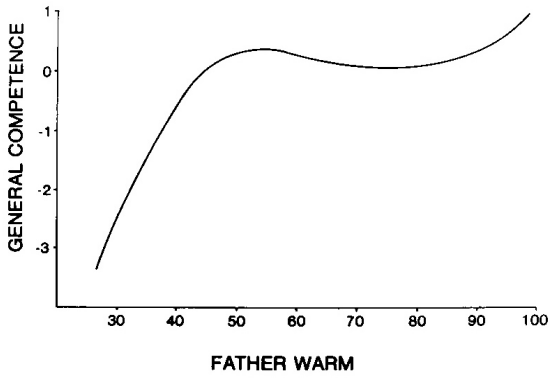

Figure 4. The 3rd-degree polynomial function relating the self-report variable Father Warm to General Competence, R^2 = .624, $F(1,26) = 4.2$, p = .05. This curve is typical of the 3rd-degree polynomials.

These findings are robust, in the sense that they also emerge for the individual (unaggregated) Q-sort variables assessing competence (see Roberts, 1983).

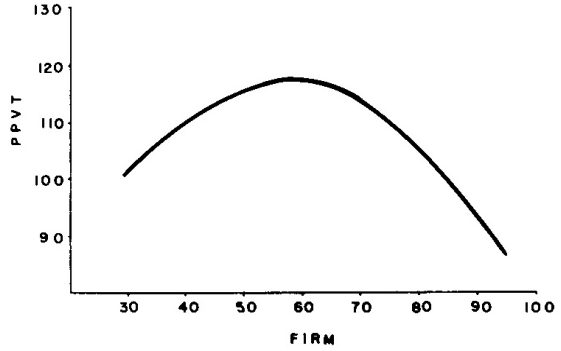

Figure 5. The 2nd degree polynomial function relating the observer-rating variable Firm to Peabody Vocabulary scores, $R^2 = .525$, $F(2,26) = 13.2$, $p < .001$. This curve is typical of the 2nd degree polynomials.

Figure 6. The 4th degree polynomial function relating the self-report variable Mother Strict with General Competence, $R^2 = .629$, $F(1,25) = 12.7$, $p < .002$.

Table 5. *Polynomial Regressions from Family Measures to Competence*

	Competence					
	General		Cooperative-Task Oriented		PPVT	
	R^2	degrees	R^2	degrees	R^2	degrees
WARMTH:						
Home observation:						
Father Responsive	.620	3***		NS		(*r* = .39**)
Mother Responsive		N.S.		NS		NS
Observer ratings:						
Warm	.611	3**		(*r* = .21)		(*r* = .29)
Responsive	.648	3****		(*r* = .27)		(*r* = .33*)
Self-reports:						
Father Warm	.624	3**		(*r* = .37**)		(*r* = .31*)
Mother Warm	.691	3****		NS		(*r* = .22)

(Table continues)

	General		Cooperative-Task Oriented		PPVT	
	R^2	degrees	R^2	degrees	R^2	degrees
CONTROL:						
Home observation:						
Father Firm	(*r* = .26)		NS		NS	
Mother Firm	(*r* = .31)		NS		NS	
Observer ratings:						
Firm	.260	2**	.219	2**	.525	2****
Directive	N.S.		NS		NS	
Self-reports:						
Father Strict	(*r* = – .38**)		(*r* = – .30)		NS	
Mother Strict	.629	4***	(*r* = – .24)		.135	2**

NOTE. Significance levels for polynomial regressions indicate goodness of fit; i.e., the given function fits the data better than one of lower degree. See Figs. 4-6 for illustrations of the tabled functions, *r*'s less than .20 not tabled; N.S. = not significant. Correlation coefficients are in parentheses.
* $p < .10$; ** $p < .05$; *** $p < .01$; **** $p < .001$.

Discussion

The practicality and importance of nonlinear modelling is supported by the emergence of the predicted types of relationships and the substantial proportions of variance that they accounted for. Moreover, the fact that similar relationships emerged across methods supports the general nature of the topological model and the underlying concept of nonlinearity.

The data also illustrate several basic conceptual difficulties. The first is the selection of variables and the trade-off between breadth and convergence. It is undoubtedly important, at least in the early stages of investigation, to have broad measures of a construct. The variables selected for this study meet this criterion. However, perhaps as a consequence, their convergence tends to be moderate, at best. Two points following from this issue of convergence can be made.

To the extent that lack of convergence reflects some real differentiation in the

underlying construct, one would expect that topological models incorporating these measures would be related but not identical. In the present sample, for example, competence differentiated into aggregates reflecting resourceful, purposive behavior and social skills (General Competence), behavior that is socially approved by adults (i.e., cooperative, friendly behavior plus the ability to keep oneself occupied), and verbal ability as assessed by a standardized test. These may indeed be distinct areas of competence, and it is plausible to suppose that the relationships between parenting and each of them are somewhat different. Thus while control has an inverted-U relationship with both General Competence and PPVT scores, warmth is sigmoidally related to the former and linearly to the latter, suggesting different versions of the underlying model (for instance, the threshold for verbal ability may be below the levels of ability sampled here). One could (and probably needs to) generate families of nonlinear models relating different aspects of warmth, control, and competence to one another. Such models would make explicit the differences and similarities in outcomes for various components of a construct, a useful exercise conceptually and a necessary preliminary to generating causal explanations.

To the extent that convergence among measures indicates underlying similarity, the issues of calibration and aggregation are raised. The basic problem, and one that will need to be addressed in future research, is how the metrics of different scales and methods should be equated. For instance, in the present study many of the warmth variables show reasonably strong intercorrelations. But how should they be aggregated? Given the different frames of reference used by trained observers and parents and the different time frames sampled by observer ratings and parent self reports, calibrating these scales by simply equating mean scores may be misleading. Calibrating such scales against the home observation variables is also not straightforward. Observation measures are not only time-limited, they also lack the context of meaning provided by ratings and self report. In this study, for example, observed maternal responsiveness shows a significant negative correlation with family size, while paternal responsiveness does not (Roberts, 1985). This suggests that mothers ignore children because they are distracted by other events, while fathers

ignore children because they don't know how to respond or don't want to. If behavioral measures indeed mean different things for mothers and fathers, then they probably should be aggregated in different ways. These are problems that need to be addressed in future research.

A related issue is the calibration of the scales (either individually or as aggregates) to the model itself. For example, while the present topological model summarizes relationships across the entire theoretical length of each dimension (running, for instance, in the case of control, from complete non-contingency to complete structure and surveillance), it is clear that the individual measures themselves do not necessarily cover this range. How, then, should they be aligned with the model? These issues of calibration and aggregation will need to be resolved by further research before it is possible to generate data precise enough to modify the model, setting in train the systematic feedback between theory and data that has been so fruitful in other disciplines.

Another difficulty, perhaps not less formidable, is the development of suitable statistical methods to manipulate data in accordance with nonlinear models. For example, the present three dimensional topological model was tested two dimensions at time, using polynomial regressions. A better test, of course, would be the regression of the observed three dimensional data points on the three dimensional surface which the model defines. Such statistical techniques could presumably be extended to *n* dimensional nonlinear models, a necessary step if models of the type described here are to be built for more complex situations.

There are, of course, practical difficulties in graphically representing *n* dimensional data by two dimensional displays, and these difficulties present a real obstacle when one attempts to build higher order nonlinear topological models. Several expedients suggest themselves, however. With the use of computer generated graphics, fourth dimensions can be represented as changes over time in a three dimensional model. In the present case, for example, developmental changes in the relationships between parenting and children's competence could be represented by a "movie", of which Figure 1 represents only a single frame. Other "fourth dimensions"

(such as peer processes) could be represented in the same manner. Additional dimensions might be added by using changes in hue and intensity of color. These possibilities suggest that the approach exemplified here can be applied to situations in which more than three factors are of interest.

The need for such an extension is suggested by the consideration that while the results of the present study imply that family interactions are major influences on general competence at this age, other factors, situational, emotional and cognitive, undoubtedly grow in importance in middle and late childhood. Parental warmth and control, for example, may grow more indirect in their impact during middle and late childhood, as they moderate other variables (such as active contact with the environment, notions of self-efficacy and achievement motivation, negative affect and learned helplessness) that become more prominent in their influence on competence. Model building of the type advocated here can both reflect these changes and aid in assessing their occurrence and importance.

Finally, two further advantages of explicit model building can be mentioned: their aid in reconciling seemingly inconsistent findings, and their help in integrating different areas of research. In the present study, for example, sigmoidal relationships were reported for warmth and general competence. In contrast, Baumrind (1971) reports an inverted-U relationship for such variables. However, she notes that in her sample high warmth was often accompanied by lax control and overprotection from stress and frustration, which was not the case in the present sample. Turning to the model in Figure 1, we find that it generates an inverted-U relationship between warmth and competence for samples like Baumrind's which are characterized at one extreme by both high levels of warmth and low levels of control, while a sigmoidal relationship is generated for samples (like the current one) in which high levels of warmth are associated with at least moderate levels of control. Thus a model of the type presented here, by explicitly incorporating sample differences, is able to integrate divergent findings.

Modelling also allows us to integrate diverse areas of research. The present topological model, for example, reflects child outcomes for both normal and clinical

patterns of parenting (e.g., abuse or neglect), and (as with authoritarian patterns, for instance), for patterns that are more common in North America, and others that are more common in other cultures.

In conclusion, the development of nonlinear models is advocated here on the grounds that such models more accurately reflect the nature of major developmental phenomena, and that building such explicit models of outcomes serves as a powerful heuristic, summarizing and integrating present knowledge and forming the basis for the construction of detailed causal and process models. While developing and testing nonlinear models involves methodological and statistical difficulties, these are not insurmountable. The example presented here, of a nonlinear model of outcomes in the socialization of competence, suggests that such models can yield predicted relationships that hold across methods and account for substantial portions of variance. Finally, such models can serve as tools for reconciling inconsistent findings and for integrating research from diverse sources.

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