A Causal Model in Curriculum Research: An Aid to Theory Building

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The causal model described here demonstrates certain linkages among the variables: principal leadership, teacher motivation, teacher performance in a curriculum system, and student achievement.

EDUCATIONAL practitioners today face challenges to commonly accepted practices in schooling from proponents of free schools, alternative schools, deschooling, and reschooling. In order to justify demands for accountability in schooling, it is imperative that the educational practitioner have available clearly defined theories to support and guide the development of curriculum policy, practice, and research. But progress in theory development and in theory-directed research in the field of curriculum has been slow, to say the least. In our judgment, one of the reasons for this state of affairs is the failure to use more vigorous rules in theory building and more sophisticated techniques in research design in the field of curriculum.

Our purpose in this article is threefold: (a) to set forth certain dimensions of curriculum theory essential for this report, (b) to illustrate how mathematical models may be used in curriculum research, and (c) to discuss how the results of that research are useful in the furtherance of curriculum theory. Our focus is upon a scientific approach to thinking about relationships among variables in the engineering of a curriculum system.

Elements common to any theory include: a set of descriptive statements which unify phenomena, a number of testable propositions which explain relationships among phenomena, and generalizations capable of predicting events encompassed by the theory. Beauchamp affirmed the logico-mathematical system to be the most systematic level in theory building, following in ascending order from the activities of classification, deduction, and prediction.[1] In the social sciences, and more particularly in the applied areas of education and curriculum, this level of sophistication in theory building is only slowly being achieved. Until recently, the social sciences were considered too complex and relationships too ill defined or variables too unmeasurable to lend themselves to quantitative analysis.

Gradually, however, theorists are finding ways to rework verbal theories so they can be recast using mathematical reasoning.

[1] George A. Beauchamp. *Curriculum Theory.* Second edition. Wilmette, Illinois: The Kagg Press, 1968. p. 14.

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For example, Johnstone reviewed the use of mathematical models developed in education for predicting future quantities,[2] and Conran reviewed the use of mathematical models developed for relating variables in the schooling process.[3] These two efforts demonstrate that progress is being made in the area of scientific theory building.

Every theory has a universal set of phenomena comprised of known, assumed, and unknown dimensions. In the model to be presented, for example, it is known at the most simple and most general level that the schooling process produces measurable learning in students. What influences learning is comprised of both known and unknown dimensions. It is generally accepted that principals lead, teachers construct a curriculum and instruct, and students acquire knowledge, concepts, skills, and values, but the degree to which these events occur and their interrelationships are among assumed and unknown dimensions. Further, all of these participants in the schooling process behave in particular ways because of the kind and degree of socialization, unique personalities, and environmental influences. Some of these influences can be identified and measured and certain relationships among them are evident; many more remain a mystery to the social scientist. The theorist uses phenomena of known dimensions to guide development of theory in the assumed dimensions, and he or she explores phenomena of unknown dimensions for which there are no adequate explanations available.

In the model to be presented, assumptions are made concerning: (a) the influences of principals' leadership upon teachers' attitudes and performance; (b) the influences of principals' and teachers' performances upon students' achievement; and (c) the influence of certain background variables upon teachers' attitudes and performance and upon students' achievement. Since concepts of curriculum design were not of concern, our model does not encompass the full range of curriculum theory; it is restricted to curriculum engineering.

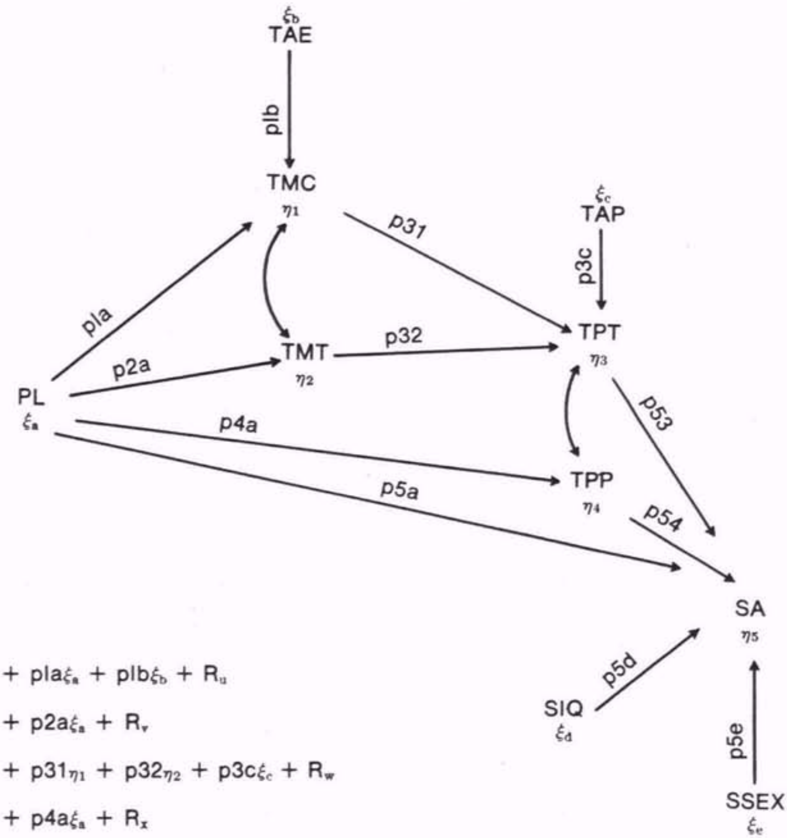
The establishment of precise meanings associated with basic concepts of curriculum is one of the major problems for the curriculum theorist. Besides the paucity of agreement within the field of curriculum, the theorist must work in a variety of disciplines; the combined result often causes fuzziness and frustration for both the theorist and the readers. The important terms for the theory content presented in this article are a curriculum, curriculum engineering, curriculum system, participation in curriculum planning, performance in a curriculum system, principal leadership effectiveness, productivity, and student achievement.

A curriculum is a written product; it contains the plan for the total educational opportunities for students in the school where it is to be implemented. *Curriculum engineering* refers to the curriculum system and its internal dynamics. It consists of all the processes necessary to make a curriculum system functional in schools: curriculum planning, implementation, evaluation, and revision. *Curriculum system* refers to the organization for both decision making and action with respect to curriculum functions regarded as a part of the total operations of schooling. *Participation in curriculum planning* is active membership in formally organized committees designed to plan a curriculum. *Principal leadership effectiveness* refers to the extent to which the principal carries out successfully the leadership process in the areas of representation, demand reconciliation, tolerance of freedom, role assumption, consideration, production emphasis, predictive accuracy, integration, and superior orientation.[4] *Productivity* refers

[2] James N. Johnstone. "Mathematical Models Developed for Use in Educational Planning: A Review." *Review of Educational Research* 44:177-201; Spring 1974.

[3] Patricia C. Conran. "A Study of Causal and Other Relationships Among Leadership, Teacher, and Student Variables in Curriculum Engineering." Unpublished doctoral dissertation, Northwestern University, Evanston, Illinois, 1974.

[4] Ralph M. Stogdill. "Manual for the Leader Behavior Description Questionnaire—Form XII: An Experimental Revision." Columbus, Ohio: Bureau of Business Research, College of Commerce and Administration, The Ohio State University, 1963. p. 3.



$$\mathrm{TMC} = \eta_1 + \mathrm{pla}\,\xi_a + \mathrm{plb}\,\xi_b + R_u$$

$$\mathrm{TMT} = \eta_2 + \mathrm{p2a}\,\xi_a + R_v$$

$$\mathrm{TPT} = \eta_3 + \mathrm{p31}\,\eta_1 + \mathrm{p32}\,\eta_2 + \mathrm{p3c}\,\xi_c + R_w$$

$$\mathrm{TPP} = \eta_4 + \mathrm{p4a}\,\xi_a + R_x$$

$$\mathrm{SA} = \eta_5 + \mathrm{p54}\,\eta_4 + \mathrm{p53}\,\eta_3 + \mathrm{p5a}\,\xi_a + \mathrm{p5d}\,\xi_d + \mathrm{p5e}\,\xi_e + R_y$$

Figure 1. Basic Theoretical Model

to the outcomes associated with teacher behavior as measured by growth in student achievement. *Student achievement* is the extent to which measurable growth in learning has taken place.

A Mathematics Model in Curriculum Research

The use of mathematics facilitates precise thought in educational theorizing. By using mathematical formulations of verbal theories, the theorist is forced to eliminate excess verbiage and to focus only on the relationships among the variables under scrutiny. Knowledge of relationships among variables, when stated precisely, is an aid to quantitative measurement and description as well as an aid to theory building. The mathematics model introduces a theoretical framework into research in curriculum engineering that permits greater complexity than usual to be introduced. This is made possible in the three ways described by Blalock: (a) through the addition of more variables; (b) through the allowance for more complex forms of relationships such as nonlinearity; and (c) through the construction of a dynamic theory dealing with time paths.[5]

The mathematics model for curriculum research herein discussed was developed in the study by Conran.[6] Because of space limitations here, our example will be restricted to those results assumed to be linear and additive from the cross-sectional data for a single grade level. Reduced-form structural equations were used to determine the strength of the assumed relationships, and the technique of path analysis was used to model demonstrated relationships.

The path diagram to illustrate assumed relationships and the structural equations used in regression analysis are presented in Figure 1. Key terms used in explaining the model and the procedure need clarification. These are causal relation, effect coefficient, endogenous variables, exogenous variables, model, parameters, and path coefficients. *Causal relation* is an assymetrical relation between two variables. *Effect coefficient*, in exact use, refers to causal determinism; a weak causal order is assumed for purposes here, and the effect coefficient refers to the measure of expected difference between two groups which are different by one unit.[7] *Endogenous variables* refer to those variables determined by forces operating within the scope of a particular model of reality while *exogenous variables* refer to those variables determined by forces operating outside.[8] Exogenous variables are considered to be predetermined for the study of a particular system. *Model* is used in this report to refer to the mathematical system of equations that represents an abstract and simplified picture of a realistic process.[9] *Parameters* are exogenous variables outside the system that present a plausible rival hypothesis concerning relationships among variables in the system. *Path coefficients* are standardized regression coefficients, or *beta* values.

Certain symbols are used to designate relationships. The single directional arrow (⟶) indicates causal ordering, and the double-headed, curved arrow (⟷) is used to indicate correlation.

The beginning steps in developing a causal model include: (a) a verbal statement of the theory explicating hypothesized relationships among variables, and (b) a statement of the causal sequence. In the model shown in Figure 1, several causal relationships are assumed: (a) student achievement (SA) is determined by the student's IQ (SIQ), student's sex (SSEX), the level of principal leadership (PL), the level of teacher performance in the curriculum system (TPT and TPP), and residual variables; (b) teacher performance is determined by teacher ability (TAP), teacher motivation (TMC and TMT), principal leadership, and residual variables; and (c) teacher motivation is determined by teacher ability (TAE), principal leadership, and residual variables. Principal leadership, therefore, is assumed to have a causal relationship with student achievement as mediated through teacher motivation and teacher performance. The higher the level of principal leadership, teacher motivation, and teacher performance, the more positive is the influence on student achievement as this is controlled for differing students' ability levels and for students' sex.

The above theoretical formulations were applied to data concerning variables in a curriculum system. Structural equations used to describe the relationships postulated among the exogenous and endogenous variables were solved using stepwise multiple regression. Preliminary steps included the use of analysis of variance and t-tests to determine differences among means for each

[5] Hubert M. Blalock, Jr. *Theory Construction: From Verbal to Mathematical Formulations*. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969. p. 4.

[6] Conran, *op. cit.*

[7] The distinction is made by Jae-On Kim and Frank J. Kahout in an unpublished paper, "Special Topics in General Linear Models." Iowa City: University of Iowa, 1974. pp. 33-34.

[8] Michael J. Brennan. *Preface to Econometrics*. Third edition. Cincinnati: South-Western Publishing Co., 1973. p. 212.

[9] Lawrence R. Klein. *An Introduction to Econometrics*. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1962. p. 11.

of the various measures, the use of correlation analysis to show the degree of relationships among variables, and hypothesizing the causal relations. Succeeding steps incorporated an initial level for student achievement in a time-series linear regression model, and illustrated nonlinear relationships in time paths derived as solutions to differential equations.

Analysis of variance and t-tests showed that there were statistically significant differences among means for each of the measures concerning the behavior of principals, teachers, and students. The correlation analyses showed that all variables had nonzero correlation coefficients with one exception in the sixth grade. Both of these preliminary results justified additional and more complex analysis.

Space will not permit a discussion of the results of data analysis for all grades and all subjects here; therefore, we will use data for second grade students in arithmetic computation as an exemplar. Solutions to the following structural equations show the results of fitting the data to the regression equations for second grade students in arithmetic computation:

1. $TMC = \eta_1 + .32PL + .74TAE + .77R_u$
2. $TMT = \eta_2 - .07PL + .99R_v$
3. $TPT = \eta_3 + .74TMC - .06TMT + .05TAP + .66R_w$
4. $TPP = \eta_4 + .64PL + .77R_x$
5. $SA = \eta_5 + .85TPP + .03TPT - 1.54PL + 1.59SIQ - .52SSEX + .20R_y$

The equations demonstrate how the effects of the exogenous and predetermined variables and parameters (right side of equations) are transmitted to the endogenous variables (left side of equations) via their components.

The observed correlations are assembled in Table 1. In addition to the measured direct effects, there were joint, or spurious, effects due to the mutual correlations of TMC with TMT and TPT with TPP. In the previous equations, and in those for other grades, principals' influence (PL) on teachers' opinions toward teaching (TMT) and toward

Effect	Variable	Standard Partial Regression Coefficients (Beta)	Coefficients of Multiple Determination (R^2)	Multiple R
η_1	PL	.32	<.01	.06
	TAE	.74	.41	.64*
η_2	PL	−.07	.01	.07
η_3	TMC	.74	.56	.75**
	TMT	−.06	.56	.75**
	TAP	.05	.56	.75**
η_4	PL	.64	.41	.64**
η_5	PL	−1.54	.17	.41
	TPP	.85	.50	.71
	TPT	.03	.55	.74
	SIQ	1.59	.81	.90*
	SSEX	−.52	.96	.98**

* $p < 0.05$
** $p < 0.01$

Table 1. Regression Coefficients for Paths to Teacher Effects and Student Achievement (ACOMP) Grade 2

curriculum (TMC) was negligible as evidenced by low *beta* values for effect coefficients. Principals' leadership did, however, exert a more powerful influence on teachers' performance as rated by principals (TPP). In the example used here to illustrate the procedure, principal leadership is shown to have a positive influence on teachers' performance in grade 2; however, other data showed principal leadership to have a strong negative influence on teachers' performance in grade 6 while influence in other grades was negligible. These findings demonstrate that additional variables need to be sought to further explain teachers' motivation and ratings of teachers' performance by principals.

Second graders' achievement in arithmetic computation was shown to be positively and strongly influenced by teachers' performance as rated by principals and by students' IQ. On the other hand, principals' leadership was shown to exert a strong, negative influence on achievement as stated while students' sex exerted a moderate influence in a negative direction. Data for other grade levels and for other subtests showed that influences differed in both magnitude and direction. However, some patterns were established. For example, teachers' self-perceptions of their performance and principals' ratings of teachers' performance were nearly always of equal magnitude and opposite in direction indicating counter-productive forces. Principals' leadership was usually positive and of high magnitude. IQ influence varied from moderate to strong.

Among the variables believed to influence teachers' self-perceptions of their performance in a curriculum system (TPT), only their attitudes toward curriculum exerted a strong influence. This was positive in all grades and *beta* values were large in all grades with one exception. The significance of the multiple R in all but grade 3 demonstrates that the variables assumed to influence teachers' self-perceptions of their performance do account for significant proportions of the variance in the effect. However, when a time-series model was used, that is, when initial achievement was considered as a variable, IQ became a significant factor in accounting for the variance in students' achievement. The influence of sex was generally of low magnitude. The direction of influence, as might be expected, varied according to subject matter. The significance of the multiple R in nearly all instances demonstrates that the variables assumed to influence achievement do account for significant proportions of the variance in the effect.

Theoretical Implications

Several implications for theory building can be derived from testing the theory presented here. *A priori* simplifying assumptions that will not distort reality need to be formulated, and multiple output functions in the schooling process need to be identified. The best way to proceed is to consider behavioral assumptions for variables in the model when making causal inferences. Such assumptions need to be tested by getting a best fit for equations to real-world data. Or it may be that the relationships are multiplicative. Further theories may be best represented by simple recursive chains that assume one-way causality or they may, more likely, be represented by models that allow for reciprocal causation and feedback loops between two or more variables.

However, even assumptions of linear and additive relations have value in theory building for two reasons: (a) they are believed to approximate reality in most situations; and (b) they permit modification to the theory when fitted to empirical data. There must be some behavioral assumptions underlying a specific type of nonlinear model, and testing helps to develop these. For example, in the larger study by Conran, the use of differential equations to trace time paths necessitated explicit assumptions to be made about principal leadership behavior and expected growth in student achievement. These assumptions permitted the formulation and testing of equations using exponentials and polynomials.

Theory may be categorized as either descriptive or normative. Sometimes descriptive theories evolve into normative theories. The attempt here was to describe real-world relationships among variables in a curriculum engineering system. When the model is fitted to new data and revised in the light of empirical evidence, it is likely that it will become predictive and normative. That is, it will be used to extrapolate future behavior on the basis of known present and past behavior. Much testing will be necessary so that a theory can be formulated to best represent real-world conditions, initially, and then to attempt to predict results. In theory building, the latter are spelled out in terms of implications, and the theory is revised when it is applied to new data so the implications can be checked out.

The use of the causal model herein described demonstrated the determined causal linkages among the variables: principal leadership, teacher motivation, teacher performance in a curriculum system, and student achievement. There is no claim that the model of reality presented is complete. In fact, research planned for the future will extend that presented here by adding variables and by testing more complex relationships. However, it is hoped that even oversimplification of processes in a curriculum system has contributed to the accumulation of knowledge and the achievement of the goal of describing a whole greater than the sum of its parts. The effort is humbly acknowledged as a beginning. □