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ABSTRACT

Causal modeling was applied to data collected in a naturalistic setting in an attempt to validate a conceptual model of teaching. These data included supervisory ratings of the variables: specifying performance objectives, diagnosing learners, selecting instructional strategies, and interacting with learners collected on 82 student teachers. Additionally, the mean number of objectives achieved by the classes of each of the student teachers was used as a measure of the fifth variable in the model, evaluating the effectiveness of instruction. A recursive causal model which described the relationship of these variables was developed and analyzed, using four linear equations. Examination of the path coefficients from these equations revealed that the variables, specification of performance objectives and diagnosing learners account for three tenths of the variance in selecting instructional strategies. Other results indicated there were low to moderate amounts of variance shared by the variables of the model. This study illustrates the application of causal modeling techniques in testing theoretical models in education using data collected in naturalistic, non-experimental settings. (Author)

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Abstract

Causal modeling was applied to data collected in a naturalistic setting in an attempt to validate a conceptual model of teaching. These data included supervisory ratings of the variables: specifying performance objectives, diagnosing learners, selecting instructional strategies, and interacting with learners collected on 82 student teachers. Additionally, the mean number of objectives achieved by the classes of each of the student teachers was used as a measure of the fifth variable in the model, evaluating the effectiveness of instruction. A recursive causal model which described the relationship of these variables was developed and analyzed, using four linear equations. Examination of the path coefficients from these equations revealed that the variables, specification of performance objectives and diagnosing learners account for three tenths of the variance in selecting instructional strategies. Other results indicated there were low to moderate amounts of variance shared by the variables in the model. This study illustrates the application of causal modeling techniques in testing theoretical models in education using data collected in naturalistic, non-experimental settings.

One nettlesome problem affecting research in teacher education has been the lack of articulation between conceptual positions and empirical validation of those positions. The distance between verbal descriptions, so common in teacher education, and empirically verified principles is vast. This situation is due in part to the language used in the theories for teacher education, the operational definitions used to define the variables to be measured, and the statistical tools used in empirical verification. An additional difficulty occurs when we attempt to use an experimental design well suited for the laboratory but ill-suited for an operating classroom. Random assignment and stringent control of independent variables are often compromised in order to gain access to "real" learners. These adjustments result in quasi-experimental designs yielding results which cannot be generalized to other settings.

Further, when tests of significance are the focus of the analysis, we tend to be satisfied with significant results, and fail to relate the variables under consideration to an overall model or theory. Alternate methods allowing causal inferences from naturalistic data have not been seriously considered. Causal techniques developed in biology and subsequently applied in economics and more recently in sociology hold promise for inferential research and model verification in teacher education (1).

The purpose of the inquiry has been to empirically validate a conceptual model of teaching using causal techniques with data obtained in naturalistic settings.

BACKGROUND ON CAUSAL MODELING

Basic to the specification of a causal model which yields accurate estimates, is a thorough knowledge of the process being modeled. For instance, all significant variables should be included in the model in a definite order. Further, the form and function of each variable in the model must be specified and there should be no interaction among the variables. Benefits from thinking causally about a problem and constructing an arrow diagram to illustrate causal processes include developing additional insights into the topic and phrasing clearer statements of hypotheses.

In discussing the tenets of causal modeling, we will consider causation in the following sense: A is the cause of B, only if B can be changed by altering A <u>alone</u>. This notion of causation implies prediction and manipulation. Additionally, to understand what is meant by "alone" in the statement, it is necessary to comprehend the concepts causal order and relevant control. Note that altering A alone does not exclude the possibility that all other causes of B are controlled or held constant. If we change A alone, this adjustment may bring about changes in many other variables that are influenced by A. These changes in other variables need not be controlled when we examine the effect of A on B (9).

The preceding explanation of causation assumes that in order to state that A is a cause of B, one must perform an "ideal" experiment in which other variables affecting B are held constant, while A if being altered. This "ideal" experiment is the underlying theoretical proposition which forms the basis for assuming the relationship between A and B. Additionally, the theoretical proposition is expressed as a linear, additive and unidirectional system. Given these guidelines, the relation between A and B can be expressed as a linear function: $B=\alpha A$, where α represents the magnitude of change in B when A changes one unit. This coefficient, α, is called the effect coefficient. The effect coefficient is equivalent to a coefficient in a regression equation <u>if</u> the assumptions of causal order and causal closure are met (10). If we interpret regression coefficients as effect coefficients by depicting these assumptions in a path diagram, then we are performing a path analysis. Causal order simply means that a sequence among the variables must occur. To illustrate, X_0 precedes X_1 and may affect X_1 but X_1 cannot affect X_0. Generally, this ordering is accomplished in terms of time of occurrence of the variable or measurement of the variable in the total system. The second assumption, causal closure asserts that for a causal relation between X and Y to occur, the covariation between these variables should not vanish when the effects of confounding variables (those variables causally prior to both X and Y) are removed. This limitation requires that we rule out all other possible causal factors (3). On what basis can we be sure we have satisfied this assumption? The answer as you might expect relates to the variables in the theoretical model or construct which provides the basis for the inquiry.

AN EXAMPLE OF CAUSAL MODELING

Theoretical Model

As the preceding discussion suggests, causal inference procedures begin with a statement of the verbal theory which mades explicit both causal order and causal closure. We have chosen a five component conceptual model of teaching (2) to serve this function. This model describes teaching as a series of sequential events requiring five distinct sets of instructional skills, that is, Specifying Performance Objectives, Diagnosing Learners, Selecting Instructional Strategies, Interacting With Learners, and Evaluating the Effectiveness of Instruction.

Specifying Performance Objectives - The decisions inherent in this element of the instructional model are instrumental in determining whether the entire instructional process can be successful in producing student learning. Restated, this idea becomes performance objectives determine th. direction and focus of instruction. When performance objectives are selected and sequenced according to a logical plan, teachers are in a position of leadership and can justify their program to responsible critics. Further beginning with objectives in planning for teaching is a well-established procedure in the literature on curriculum development (14, 15, 16).

Diagnosing Learners - Teachers need information regarding a learner's readiness to begin a proposed new instructional sequence. The readiness of learners in this instance pertains to whether they have attained relevant prerequisite knowledges and skills necessary to acquire the objectives established for an instructional sequence (6,8). Bypassing this step in an effort to save instructional time is false economy, since the result may well be frustrated, bored and unmotivated learners. When adequate diagnostic information is available, instructional plans can be developed that meet the informational and emotional needs of the learners.

Selecting Instructional Strategies - In selecting instructional strategies, teachers are encouraged to structure activities that are consistent with the identified performance objectives, the entry levels of the learners, and the events of instruction espoused by Gagne & Briggs (7). In a sense, selecting instructional strategies is analogous to generating directional research hypotheses. A strategy is created from a wide range of possible approaches which, in the teacher's mind, will likely bring about learner attainment of the performance objectives. The appropriateness of this strategy is "tested" during the implementation and evaluation phases of instruction. Justification for the position of this component in the model again is drawn from literature on curriculum development (14, 15) and instructional design (4, 8).

Interacting with Learners - This component represents the "doing or implementation phase" of the instructional model. The elegance of the instructional plan is academic if the timing and continuity of the classroom activities are interrupted creating disorder and predictable management problems. Thus, acquiring the ability to interact effectively with learners is, perhaps, the most difficult set of skills for new teachers to attain. Mastering these skills requires considerable practice in actual classroom settings, and serves to justify the emphasis on the student teaching experience in teacher preparation programs. Pragmatically, this phase occurs after the instructional unit has been planned and developed. Thus, the position of this component in the model is established by logical and practical considerations.

Evaluating the Effectiveness of Instruction - This final component serves to gather evidence during and after the teaching of an instructional unit to determine whether the plan "worked." A review of each component in the instructional model is undertaken in this component. Representative questions to illustrate this review include: Were the performance objectives appropriate? Were the pretests really diagnostic tools? Did the instructional strategies incorporate the events of instruction? Were classroom management procedures sufficient to maintain a favorable learning environment? Were the evaluation tools valid for assessing learner growth and program effectiveness? These questions are characteristic of summative evaluation concerns (12) and product evaluation (13). Thus justification for the position of this final component in the teaching model is drawn from the professional literature on evaluation.

This model of teaching provides a framework that encourages the development of individual teaching styles. Individualized styles are encouraged because evaluation of instruction is based ultimately on learner attainment of performance objectives. Given this operating principle, teachers and teachers in preparation are free to choose procedures from their own repertoires that they believe will result in high levels of learner performance. Further, teacher responsibility is well served by this model. This responsibility comes not because of the teacher's adherence to a set of "ideal role behaviors," but rather in adapting instructional practice, as necessary, to help learners achieve performance objectives that have been selected.

Causal Model

Translating this conceptual verbal model into hypothetical causal relations is the function of the diagram provided in figure 1. As indicated previously, the path diagram indicates linear, additive relations among the five variables which are included in the model.

place figure 1 about here

Only the initial variable in the model is exogenous, that is, X_1 is not influenced by the other variables in the model. The remaining four variables, X_2, X_3, X_4, X_5, are considered to be endogenous and as such are determined completely by variables within the model as well as the residual variables, i.e., R_t, R_u, R_v, R_w. These residual variables represent the effect of unspecified variables which cause variation in the endogenous variables. The path coefficients (P_{ij}) represent the effect of one variable (X_j) on another (X_i).

Once the path model has been specified, a set of structural equations can be developed and analyzed to provide numerical estimates for the path coefficients. It is also noteworthy that one fully defined structural equation can be developed for each endogenous variable in the model. In the case of our path model for teaching, four structural equations have been developed:

$$X_2 = P_{21}X_1 + P_{2t}R_t$$

$$X_3 = P_{31}X_1 + P_{32}X_2 + P_{3u}R_u$$

$$X_4 = P_{43}X_3 + P_{4v}Rv$$

$$X_5 = P_{52}X_2 + P_{53}X_3 + P_{54}X_4 + P_{5w}R_w$$

These structural equations then can be analyzed with simple multiple regression techniques. The path coefficients, P_{ij}, which are associated with various arrows in figure 1 are standardized Beta coefficients: that is $P_{21} = B_{21}$. *These path coefficients represent the proportion of the standard deviation of the dependent variable directly accounted for by an independent variable when the influence of all other variables are removed (11).* Standardized Beta coefficients from the four linear equations representing the various path coefficients in figure 1 are presented in the results (Table 1).

Background

The estimates in table 1 are based on data collected from a sample of 32 secondary level student teachers who participated in a full semester-full day student teaching program offered by the department of educational curriculum & instruction at Texas A&M Unversity. During this experience, each student teacher is required to develop and implement two instructional units in a manner consistent with the model of teaching being validated in this analysis. Evaluation of student teachers in this program includes supervisor ratings based on in-class observations, supervisor assessments of instructional materials produced by the student teacher and cognitive gains by learners of the student teachers. Generally, six supervisor ratings are completed during a semester. These ratings are recorded on an Evaluation Profile instrument. This instrument is used to obtain instructional effectiveness ratings of the student teacher's performance. The profile consists of thirty Kikert type items divided into two categories, that is, instructional competencies (23 items), and personal and professional competencies (7 items). Each item on the scale is referenced to a performance objective in the student teaching program. Further, the instructional skills addressed on this instrument are compatible with the skills and knowledges stressed in the conceptual model of teaching on which this inquiry is based. An alpha coefficient, $\alpha=.94$, determined for this instrument suggests a high degree of internal consistency among responses to the various items.

A second rating scale, the Curriculum Context Checklist, was used to provide university supervisor ratings of the curricular units developed by the student teacher. Values from this scale provide data for the variable, planning effectiveness of the student teacher. This instrument contains a 5 choice scale identical to the scale of the evaluation profiles. Individual items of this instrument identify components of the curriculum unit, e.g., general goals, focusing generalizations, concept list, diagnostic component, instructional strategies.

A third instrument, Summary Evaluation of Unit, is completed by the teaching candidate immediately after completing the instruction associated with each unit. This form requires an estimate of the achievement level and socioeconomic level of the learners in addition to the actual number of class periods required to teach the unit. Perhaps the most significant information from student teaching is recorded on this form by the teaching candidate; these data being achievement information (learner attainment of individual unit objectives, pretest scores, and unit posttest scores). Criterion-referenced tests developed by the student teacher are used to provide these learner attainment data. These instruments, unique for each unit and each student teacher, represent a strength yet potential limitation in the design of this investigation. As a strength the student teacher, with guidance from classroom and university supervisors, develops tests related directly to the outcomes established for the performance objectives in each unit. Prior learning, extenuating classroom situations, and the abilities of the learners are taken into account in establishing both the objectives and the corresponding criterion tests. Considering these factors, the cognitive attainment measure indeed should sample the behavior called for by the performance objectives of the unit.

A potential limitation of candidate-developed criterion-referenced tests stems primarily from the lack of information on the reliability and validity of the respective instruments. Conventional reliability procedures appropriate for norm-referenced tests are not determined on the various criterion-referenced tests because the function of these tests (to determine an examinee's level of functioning with respect to a stated criterion) is not consistent with the function of norm-reference tests (determine an individual's performance with respect to the performance of others in the group). Thus, although we are concerned, we are not unduly alarmed by the absence of these values. Validity of criterion-referenced instruments on the other hand, can be assessed by determining the logical relation of the performance objectives and the individual test items. Fortunately, this validity check was conducted by the classroom and university supervisor on each candidate's test before the instrument was administered to the learners.

Values for the five variables in the path model were derived from the Curriculum Context Checklist completed on the second instructional unit taught by the student teacher (X_1, X_2, X_3), the final rating on the Evaluation Profile instrument (X_4), and the Summary Evaluation of Unit (X_5). Additional detail regarding the nature of the program, as well as copies of the scales and indices used in this inquiry are presented in Denton and Norris (5).

Results

Solutions to the four structural equations are summarized in table 1. As mentioned previously the numerical value of the path coefficients are the standardized regression coefficients for the independent variables in the equation.

The influence of objective specification on diagnostic strategies is modest given the coefficient of determination, $R^2=.043$, and path coefficient, $P_{21}=-.207$. These values however, do support the hypothesized linkage between these variables in the model, yet do not rule out the influence of unspecified variables contributing to the nature of the diagnostic procedure adopted by the teaching candidates.

The path coefficients, indicating the effect of performance objective specification on subsequent instructional strategies, $P_{31}=-.106$, and diagnostic techniques on instructional strategies, $P_{32}=.521$, suggest some empirical support for these linkages in the model. Interestingly, these two variables account for 30.5% of the variance in the instructional strategies variable. Conversely, the hypothesized linkage between the variables instructional strategies (X_3) and interacting with-learners (X_4) failed to produce an empirical relation. Further, the total influence attributed to diagnosis, instructional strategies and interacting with learners on evaluation is quite modest, i.e., $R^2=.087$. Effects of diagnostic techniques on evaluation, $P_{52}=.201$, instructional strategies on evalution, $P_{53}=-.339$ and interaction with learners on evaluation, $P_{54}=-.074$, reveal modest to very low influences between the variables in these various paths.

place table 1 about here

Given these values in table 1, residual path coefficients for the endogeneous variables were calculated, i.e., $P_{2t}=.98$, $P_{3u}=.83$, $P_{4v}=1.00$, $P_{5w}=.96$. These residual coefficients are determined by applying the formula $P_{residual}=\sqrt{1-R^2}$ where R^2 is the coefficient of determination or variance accounted for by the independent variables in each of the structural equations.

As mentioned earlier, the residual path coefficient indicates the effect of all unmeasured variables not included in the model that cause variation in the dependent variable. Examining the coefficients of determination (R^2) in table 1, reveals one of the structural equations is composed of variables which explain over 30% of the variance in the dependent variable under consideration. Conversely, one equation emanating from this model resulted in an R^2 of zero suggesting a limitation in the model specification and/or data collection procedures for the variables in the equation.

Germane to our discussion regarding the adequacy of the path model is the determinination of the direct and indirect effects that one variable has upon another. Path analysis enables the decomposition of the correlation between any two variables into a sum of simple and compound paths. While there are a number of decomposition approaches, we have applied a technique developed by Sewall Wright as cited in Asher (3). Wright's approach consists of two definitions and three instructions as to how a correlation is decomposed.

The definitions are:

1. Any correlation between two variables can be decomposed into a sum of simple (direct) and compound (indirect) paths.

2. A compound path is equal to the product of the simple paths comprising it.

The corresponding instructions attributed to Wright are:

(a) no path may pass through the same variable more than once;

(b) no path may go backward (against the direction of) an arrow after the path has gone forward on a different arrow;

(c) no path may pass through a double-headed curved arrow (representing an unanalyzed correlation between exogenous variables) more than once in any single path.

Applying these definitions and instructions to the path coefficients listed in figure 1, decomposition of the correlations between the variables in the model have been accomplished and are reported in table 2.

place table 2 about here

The decomposition of the correlation provides a way to test the adequacy of the model if some linkages have initially been omitted. If the model is specified correctly, the zero order correlation between any two variables should be numerically equal to the sum of the simple and compound paths linking the two variables. If the values are not equal, then the model may not be specified appropriately and be in need of revision. Further, if the zero-order correlations between variables in the model are zero or nearly so, then adjustments may be necessary. Similarly, if correlations between variables which are not connected by paths in the model greatly exceed zero, specification concerns may be signalled.

Examining the values in table 2 reveals possible limitations in the present model given the aforementioned guidelines. For instance, the path coefficients between X_3-X_4 (P_{43}=-.016), X_4-X_5 (P_{54}=-.074) suggest errors regarding the causal links between Instructional Strategies(X_3) and Interacting with Learners (X_4), between Performance Objectives (X_1) and

Instructional Strategies (X_3), and between Interacting with Learners (X_4) and Evaluation (X_5), respectively. It cannot be determined from the information we have whether the difficulties lie with model specifications, variable measurement or a combination of these conceptual constructs. Yet we do know where to direct our attention in re-examining the model.

As the preceding statements reveal, path analysis procedures provide us with the means to check the conceptual associations in our model of teaching. While the linkages with the components, Interacting with Learners, appears to be in need of review, other aspects of the model appear to be reasonably sound.

SUMMARY

This paper has addressed one type of causal model involving one-way causation. The structural equations in this paper are linear and focus on relations across the five components of a model of teaching. Other forms of causal modeling are possible which involve reciprocal causation under certain conditions, but these non-recursive techniques have not been addressed.

Causal modeling procedures provide powerful methodological tools for relating theory and research in naturalistic settings. Moreover, these techniques enable a set of causal relations to be hypothesized on the basis of a theoretical framework. Subsequent to this conceptualizing effort, linear regression equations based on the set of hypothetical relations are developed and treated statistically. Values obtained from this treatment are then used as numerical estimates of the hypothesized relations. Thus causal modeling permits conceptual theories in education to be transformed into their quantitative equivalents for empirical testing. Perhaps through the use of these methods, the gulf between verbal and quantitative constructs in teacher education can be reduced resulting in better theories for teaching and preparing teachers.

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Table 1

Standardized Regression Coefficients (Path Coefficients) for the Four Structural Equations Related to the Model of Teaching

Dependent Variable	Independent Variable	Path label (P_{ij})	Standardized Regression Coefficient (B)	Coefficient of Determination (R^2)
Diagnosis (X_2)	Performance Objectives	P_{21}	-.207	.043
Instructional (X_3) Strategies	Performance Objectives	P_{31}	-.106	.305
	Diagnosis	P_{32}	.521	
Interacting (X_4) with Learners	Instructional Strategies	P_{43}	-.016	.000
Evaluation (X_5)	Diagnosis	P_{52}	.201	.087
	Instructional Strategies	P_{53}	-.339	
	Interacting with Learners	P_{54}	-.074	

Table 2

Correlation Decomposition Table for Relations Among the Five Variables Included in the Model of Teaching

Variables	Zero-order Correlation(r_{ij}) (A)	Causal Direct (B)	Causal Indirect (C)	Causal Total (D)	Spurious (A-D)
X_1-X_2	-.207	-.207	000	-.207	000
X_1-X_3	-.213	-.106	-.107	-.213	000
X_2-X_3	.542	.521	000	.521	.021
X_3-X_4	-.016	-.016	000	.016	000
X_3-X_5	-.229	-.339	.001	-.338	.109
X_4-X_5	-.074	-.074	000	-.074	000
X_2-X_5	.020	.201	-.177	.024	.004
X_1-X_4	.106	**0	.002		
X_1-X_5	.115	**0	-.006		
X_2-X_4	-.030	**0	.008		

**Direct causal effects between these variables were not calculated, since they were not included in the path model. The causal effect of these variables pairs is assumed to be 0 since they were not included in the path model.

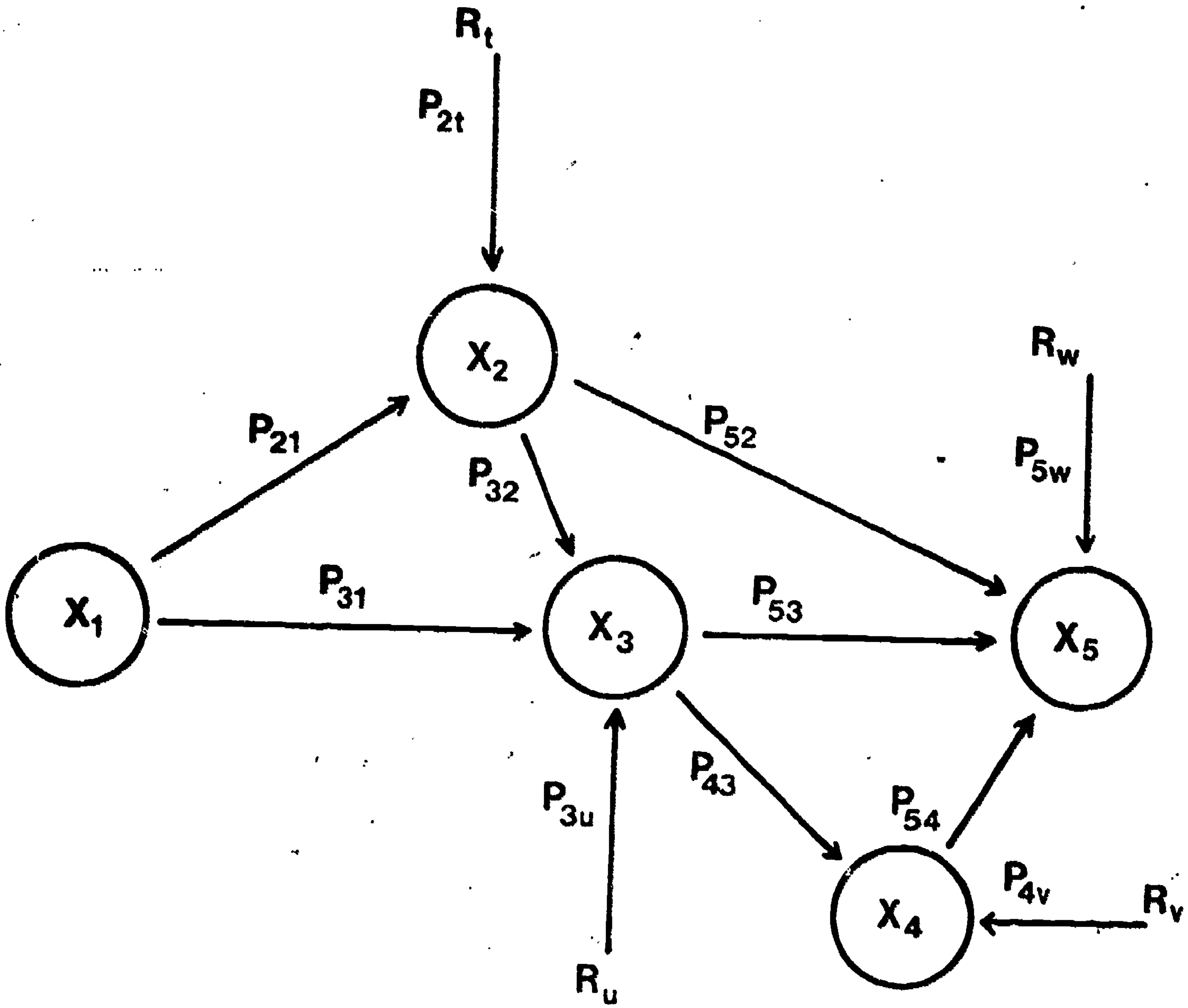

Figure 1

Recursive Path Model for a Model of Teaching

X_1 = Performance Objectives Component, X_2 = Diagnosis Component,
X_3 = Instructional Strategies Component, X_4 = Interacting with Learners Component,
X_5 = Evaluation Component, P_{ij} = Path Coefficients