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ABSTRACT

This study used the Bayesian Theorem and cost/effectiveness analysis to measure the short and long range effectiveness and minimum costs of individualized instructional units constructed by educational development officers for use with low-income students at four North Carolina technical institutes designated as developing institutions. Students experiencing the individualized instructional units in the technical institutes responded to opinionnaires measuring their judgments of value of each instructional unit, and to questionnaires measuring the degree of behavioral objectives achieved per unit. A cost analysis procedure calculated the costs for each instructional unit. Student value judgments of each instructional unit formed the prior distribution of the Bayesian Theorem and the degrees of behavioral objectives achieved per unit made up the sample distribution of the model. Variables combined in the joint probability distribution generated utility probabilities (value) for each unit, and costs per unit combined with the utility values for each unit formed expected opportunity loss values in utiles from the conditional worth matrix. Utility and expected opportunity loss values indicated those instructional units with maximal effectiveness as well as those requiring revision. This model is an inexpensive effective planning procedure which demonstrates accountability in a variety of educational programs and systems. (Author)

An Evaluation of Individualized Instructional Units using the Bayesian Theorem in Two-year Technical Institutes Designated as Developing Institutions

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ABSTRACT

An Evaluation of Individualized Instructional Units Using the Bayesian Theorem in Two-Year Technical Institutes Designated as Developing Institutions

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An important operation of educational planning is the establishment of measures of curriculum effectiveness. The types of curriculum effectiveness measures used in instructional systems include subjective and objective data consisting of personal values, degrees of objectiveness attained, and costs. Among the various planning or systems models used to analyze and to predict events in educational and other people-changing systems are the Bayesian theorem and cost/effectiveness analysis.

The current study uses the Bayesian theorem and cost/effectiveness analysis to measure the short and long range effectiveness and minimum costs of individualized instructional units constructed by educational development officers for use with low-income students at technical institutes designated as developing institutions. Students experiencing the individualized instructional units in the technical institutes responded to opinionnaires, measuring their judgments of value of each instructional unit and questionnaires, measuring the degree of behavioral objectives achieved per unit. A cost analysis procedure developed calculated the costs for each instructional unit. Student value judgments of each instructional unit formed the prior distribution of the Bayesian theorem and the degrees of behavioral objectives achieved per instructional unit made up the sample distribution, $P(A/B_i)$, of the model. The variables combined in the joint probability distribution generated posterior probabilities (utility) $P(B/A_i)$ for each instructional unit. Costs per unit combined with the utility values for each unit formed expected opportunity loss values (EOL) in utiles from the conditional worth matrix.

Individual instructional units in given curricula with the highest utility values, $P(B/A_i)$, and the lowest expected opportunity loss values in utiles were the optional choice in terms of cost and effectiveness. Utility and expected opportunity loss values generated over a three-year period indicated those instructional units with maximal effectiveness as well as those requiring revision. The current model is an effective, inexpensive planning procedure which demonstrates accountability in a variety of educational programs and systems.

Introduction

An important operation of educational planning is the establishment of measures of curriculum effectiveness. The types of curriculum effectiveness or evaluation measures include subjective and objective data consisting of personal values and program costs. These data bases enable educational development officers as well as other professionals opportunities to assess the degree of attainment of educational objectives. Among the various models used in educational planning to analyze and to predict various events in educational and other people-changing systems are the Bayesian Theorem used as a curriculum or program evaluation procedure and cost/effectiveness analysis used for curriculum or program revision and intra-program comparisons.

The purpose for using the Bayesian Theorem or often called The Bayesian Statistical Decision Theory in curriculum evaluation is to estimate both short and long range program effectiveness. The Bayesian Theorem synthesizes prior information in the form of personal probabilities and current information consisting of sample data to form a posterior probability indicating the degree of certainty of an event. The theorem with its use of prior or personalistic probabilities provides a model for the revision of judgments in the light of new information. The purpose for using cost/effectiveness analysis measurement is to relate costs of particular instructional components to their effectiveness or value. Cost/effectiveness analysis identifies program components possessing increased effectiveness and diminishing costs. The theoretical basis of cost/effectiveness in public education is the equality of selling price and program costs. The current model of cost/effectiveness utilizes this "Break-even" concept.

The Bayesian Theorem

A lengthy discussion of conditional probability and the Bayesian Theorem is not possible in the current paper. For an in-depth orientation to these topics, the writers recommend Novick and Jackson's (1974) and Schmitt's (1969) books. A succinct description of the Bayesian Theorem is reported below.

The conditional probability of event A, given the sample space B is as follows:

$$P(A/B) = \frac{P(A \text{ and } B)}{P(B)}, \quad P(B) \neq 0 \qquad (1)$$

When events A and B are independent, P(A and B) = P(A) . P(B), if $P(B) \neq 0$. therefore,

$$P(A/B) = \frac{P(A) \cdot P(B)}{P(B)} = P(A), \; P(B) \neq 0 . \qquad (2)$$

Then, given the definition of conditional probability and the union of mutually exclusive events, the theorem can be formulated. Given the mutually exclusive events B_1, B_2, . . . B_n, each with non-zero probability, whose union is the sample space, then

$$P(A) = P(A/B_1) \cdot P(B_1) + P(A/B_2) \cdot P(B_2) \ldots \qquad (3)$$

$$\ldots P(A/B_n) \cdot P(B_n) = \sum_{i=1}^{n} P(A/B_i) \cdot P(B_i)$$

because the probability of event B_i, given A, is

$$P(B_i/A) = \frac{P(A/B_i) \cdot P(B_i)}{P(A)} \qquad (4)$$

and since $P(A) = \sum_{i=1}^{n} P(A/B_i) \cdot P(B_i)$

then Bayes' Theorem follows by substituting equation 3 in the denominator of the equation:

$$P(B_i/A) = \frac{P(A/B_i) \cdot P(B_i)}{\sum_{i=1}^{n} P(A/B_i) \cdot P(B_i)} \qquad (5)$$

Some basic definitions will clarify the theorem. The probability of event, $P(B_i)$, is defined as an a-priori probability, which is a subjective or personal probability based on the rational judgment of the individual assigning the probability. In using the theorem, the individual assigns a subjective estimate, $P(B_i)$, about an event, then makes an observation, $P(A/B_i)$, and calculates the a-posteriori probability, $P(B/A_i)$. The observation, $P(A/B_i)$, is the probability of A under condition B_i. Collectively, these probabilities are the observed sample distribution. The posterior probabilities, $P(B/A_i)$, calculated from the Bayesain Theorem are used in subsequent experiments to update probabilities. That is, the posterior probabilities of experiment I become the prior probabilities, $P(B_i)$, of experiment II, etc.

Applied to curriculum evaluation, the theorem generated utility and cost/effectiveness values on individualized instructional units developed by educational development officers in four North Carolina technical institutes. The evaluation study spanned three years with support from Title III, The Basic Institutional Development Program.

More specifically, let each individualized instructional unit or program element be designated $B_1, B_2, B_3 \ldots B_n$. Each curriculum is designated $A_1, A_2, A_3 \ldots A_n$. Then, the symbol, $P(A/B_i)$, is defined as the probability of program A given B_i. Each value of $P(A/B_i)$ is actually a scaled value (questionnaire) measuring the degree of behavioral objectives achieved per instructional unit. These values represent the sample distribution, $P(A/B_i)$, of the Bayesian Theorem. Then, each program element within a curriculum forms the prior distribution, $P(B_i)$. Actually, these are judgments of program worth or value measured on an interval scale (opinionnaire), forming the prior distribution of the Bayesian analyses. The degree of specific behavioral objectives achieved per unit combined with the normalized value judgments through the Bayesian Theorem generates the posterior probabilities or utility values. The utility value of each unit is intergrated with unit costs in the expected opportunity loss model providing cost/effectiveness indices. Basically, the expected opportunity loss (EOL) is the product of the Bayesian utility values and the absolute value of the difference between costs and selling price, known as conditional opportunity loss (COL). The expected opportunity loss (EOL) value for a given program element or individualized instructional unit is the sum of the products of each probability and the con ctional opportunity loss (COL). If costs and selling prices are equal, then procedures for determining expected opportunity loss (EOL) values are trivial. The basic model for combining the utility of each program element; let's say P_1, which costs C_1 dollars is

$$\sum_{i=1}^{n} \mu_i \quad (S_i - C_1)$$

utiles, the minimum expected loss for a set of elements or units in a program. The minimum expected opportunity loss is the best decision or optimal solution if one is selecting instructional units or program elements for continued use. If the differences between costs and selling prices are unequal, more analyses are needed

Curriculum Evaluation

The evaluation format utilizing the Bayesian Theorem and a cost/effectiveness model is based on Tanner's (1971) program and the writers' applied research in curriculum programs in four technical institutes of The North Carolina Community College system. The discussion, thus far, has not covered the use of these models in a program context. While the Bayesian and expected opportunity loss cost/effectiveness models themselves generate interest to researchers and enlightened administrators, their use as a viable curriculum and program evaluation procedure encourages systematic planning and decision-making in all areas of instructional systems.

Four technical institutes in North Carolina formed a consortium and received funding from Title III, The Basic Institutional Development Program, for curriculum development. The mission of the curriculum development program was to develop individualized instructional units in the curriculum programs of the four technical institutes: (1) Wilson County Technical Institute, (2) Pitt Technical Institute, (3) Edgecombe Technical Institute and (4) Roanoke-Chowan Technical Institute. Having the designation of Developing Institution by the Title III program, the four institutes used the curriculum development program to alleviate weaknesses in their instructional systems. Educational development officers used the Systems Approach to Individualized Instruction in developing the instructional units. Basically, the systems approach to developing individualized instructional units involves six components: (1) rationale, (2) objectives, (3) pre-test, (4) learning activities, (5) post-test and (6) revision. Theoretically, individualized instructional units based on the systems approach permit students to engage in learning activities leading to the attainment of specific performance objectives. In addition, the focus of the instructional units is on what the student has learned using the instructional units. One implication made from the use of this approach is accountability for results in curriculum programs of developing institutions.

The philosophy of program accountability inherent in the management-by-objectives and results procedure used by the consortium's coordinating institution, Wilson County Technical Institute, prompted the application of the above curriculum effectiveness models on individualized instructional units in curriculum programs. The rationale for using the models was to use an evaluation procedure determining program utility (value) and to intergrate the variables of utility and costs. The three sets of major variables used in the models are the degree of objectives achieved, forming the sample distribution, $P(A/B_i)$; the relative contribution or value of each instructional unit in a given instructional program, forming the prior distribution, $P(B_i)$; and the cost (dollars) per unit.

The primary assumption of the models as Tanner (1971) indicated is that utility (the posterior probability) is a function that reveals mathematically the relationship between values or preferences and objectives under the condition of uncertainty. Utility (posterior probability) is removed from the classical concept involving only dollars values. The judgments of program worth or value are determined for each instructional unit on an interval scale as measured by an opinionnaire. The degree of specific objectives achieved per unit as measured by a questionnaire is combined with the normalized value judgments through the Bayesian process to determine utility or the posterior probability. The posterior probability (utility) is then intergrated with the costs of each instructional unit in the expected opportunity loss model providing cost/effectiveness indices. Specifically, the posterior probabilities, $P(B/A_i)$ of each unit are multiplied by the conditional opportunity loss (COL) values (in dollars) to form expected opportunity loss (EOL) values (utiles). The objective of the expected opportunity loss (EOL) analyses combining utilities and conditional opportunity loss values is to determine the minimum cost and maximum utility of instructional units when compared with others in the same curriculum program. The unit with the lowest EOL value in utiles is the most valuable component in terms of cost and effectiveness. Since one central concern of administrators is the use of instructional components with minimal costs and maximum effectiveness, the current models are appropriate for educational planning. Such was the case in assessing the value and costs of individualized instructional units developed in the four institutes.

Over a three year period (1973-1974 - 1975-1976) educational development officers developed over 100 individualized instructional units for a large number of vocational and technological curricula in the four technical institutes. Procedures used to develop, evaluate, and revise the instructional units followed a standardized format described below.

Initially, the educational development officers and faculties cooperatively developed instructional units for particular curricula. The systems approach with its six components was the framework for instructional development. A cost analysis procedure used by the educational development officers determined the cost (dollars) of each instructional unit The cost procedure considered instructional and staff salaries, supplies, and materials, maintainence costs and travel in the calcualtion of a total cost per unit figure.

The educational development officers and faculties used the new instructional units in regularly scheduled courses at the institutes. In some situations, educational development officers actually taught the classes since they desired to be effective teachers as well as curriculum developers.

For the evaluation study, the educational development officers kept records in each course of the students who used each of the new instructional units. Some instructional units had little face validity with students because of various weaknesses in their structure (e.g. high level of difficulty, vague content, and broad objectives). These units were withdrawn from the courses and not used in the evaluation study.

In the spring of each of the three years, the educational development officers and Title III coordinator randomly selected 77 individualized units for analysis. Costs of each unit matched costs orginally tabulated on the cost analysis sheets. Then, for each individualized instructional unit selected, the Title III coordinator developed two instruments to assess the value or contribution of the instructional unit in the context of the particular curriculum program. First, an opinionnaire measuring the degree of contribution (value) each unit has to the successful achievement of a particular course consists of a 32 point scale similar to the one introduced by Likert (1967). The data from the 32 point scale are normalized per n instructional units in each curriculum program and represents the prior distribution, $P(B_i)$ (Appendix A). Second, a questionnaire measuring the degree of behavioral objectives achieved for each unit represents the percentage achieved per program element (instructional unit) (Appendix A). Each percentage becomes a component in the sample distribution, $P(A/B_i)$. It is important to note that only one objective per unit is necessary to evaluate the instructional units. Also, each unit may have more than one objective.

Next, the educational development officers randomly selected students from curricula who used the individualized instructional units chosen. In the spring of each of the three years (1973-1974 - 1975-1976), the students selected and filled out both the opinionnaires and questionnaires. A software program on the Bayesian and cost/effectiveness models installed in the computer facilities at North Carolina State University by Dr Herbert Kirk calculated the data reported below.

Data analyses of all the instructional units used over the three year period (1973-1974 - 1975-1976) is beyond the scope of the current paper. To illustrate the curriculum effectiveness procedures described above, Bayesian and cost/effectiveness data of eight individualized instructional units from three curriculum programs depict effectiveness measurement in curriculum programs. These data are reported in Tables 1 and 2.

Table 1: Utilities of Individualized Instructional Units over three Program Evaluations (1973-1974 - 1975-1976)

Course	Instructional Unit	Initial Prior Distribution $P(B_i)$	Posterior Distribution (Utility) 1973-1974 (a) $P(B/A_i)$	Posterior Distribution (Utility) 1974-1975 (b) $P(B/A_i)$	Posterior Distribution (Utility) 1975-1976 (c) $P(B/A_i)$	Mean Utility $P(B/A_i)$
English	Communications Skills I	.40	.44	.43	.56	.48
	Communications Skills II	.35	.35	.35	.43	.38
	Communications Skills III	.25	.23	.22	–	.23
Radiology	Radiographic Anatomy	.55	.60	.64	.67	.63
	Radiographic Physics	.45	.39	.36	.32	.36
Trig-onometry	Introductory Terms	.33	.34	.35	.34	.34
	Trig. Tables	.33	.33	.33	.33	.33
	Trigonometric Functions and the Slide Rule	.33	.33	.32	.33	.33

(a) Posterior distribution in 1973-1974 study and the prior distribution in the 1974-1975 analysis.

(b) Posterior distribution in the 1974-1975 study and the prior distribution in the 1975-1976 analysis.

(c) Posterior distribution in the 1975-1976 study and to be used as the prior distrubition in 1976-1977 analysis.

– Instructional unit not used in 1975-1976 analysis.

Table 2: Costs and Expected Opportunity Loss Values for Individualized Instructional Units over three Program Evaluations (1973-1974 - 1975-1976)

Course	Instructional Unit	$Cost	EOL Value (a) 1973-1974	EOL Value (b) 1974-1975	EOL Value (c) 1975-1976	Mean EOL
English	Communications Skills I	$900.00	196.78	200.92	239.40	212.37
	Communications Skills II	$350.00	376.10	371.44	310.60	352.71
	Communications Skills III	$950.00	223.90	228.56	–	228.23
Radiology	Radiographic Anatomy	$800.00	278.22	252.87	230.52	260.53
	Radiographic Physics	$100.00	421.78	447.13	469.48	446.13
Trig-onometry	Introductory Terms	$150.00	19.81	19.61	19.65	19.69
	Trigonometry Tables	$150.00	19.81	19.61	19.65	19.69
	Trigonometric Functions and the Slide Rule	$ 90.00	40.19	40.39	40.00	40.16

Inspection of the utilities and cost/effectiveness values (in utiles) in the instructional units of the three courses reveal some rather interesting results. In the English course, for example, the first instructional unit with the highest mean utility value and the lowest mean expected opportunity loss value is clearly the most valuable in terms of cost and effectiveness. The other two units in the English course were not as valuable in terms of cost and effectiveness, since both had lower utilities and higher expected opportunity loss values. Actually, the third unit, Communications Skills III, was revised by the educational development officers and will be used again by the institutes.

In the radiology course, the first unit, radiographic anatomy, had the higher utility values and the lower expected opportunity loss values when compared with its companion unit, radiographic physics. Interestingly enough, the radiographic anatomy package utilizing expensive multi-media sound and slide presentations was not commercially produced, but the product of educational development officers. The commerically developed, less expensive radiographic physics unit failed to have greater cost/effectiveness with a mean utile value of 446.13.

Data collected on the trigonometry course tended to be very similar with no clear-cut patterns emerging. While the first instructional unit, introductory terms, had the highest utility value when compared with the other two units, the mean expected opportunity loss values of the first two units were equal and considerably lower than the value for the third unit.

Another interesting condition is the similarities of the utilities and expected opportunity loss values over the three year span. One explanation for the similarities is the consistent up-dating of the prior distribution $P(B_i)$, with the posterior distribution, $P(B/A_i)$ from the previous year's analysis and the use of the identical cost figure of each instructional unit. The frequent up-dating of the prior distribution, $P(B_i)$, through posterior probabilities, $P(B/A_i)$, merely add data to the group's value judgments and make the prior distribution, $P(B/A_i)$, less dependent on the original prior distribution, $P(B_i)$.

The evaluation procedure delivers a systematic plan based on both subjective probabilities and costs to administrators and curriculum specialists. The procedure produces data on how students think they will function as a result of experiencing specific instructional units. Cognitive data such as standardized achievement and criterion-referenced tests may be used in the sample distribution, $P(A/B_i)$, of the Bayesian model. Also, the Bayesian and cost/effectiveness models may be applied to other evaluation programs in postsecondary institutions.

One result of the current study is that a systematic attempt to measure curriculum effectiveness in programs funded by Title III, the Developing Institutions Act, was made. The authors contend that the assessment of program effectiveness is a giant step toward demonstrating program accountability with federal monies. In the vernacular, trying to develop curricula with maximum effectiveness with a minimum of costs is "Trying to bring off what you stated in the project you would bring off".

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APPENDIX A

Roanoke-Chowan Technical Institute

Questionnaire

Course: Physics

Directions: Below is a list of instructional units in Physics which you have studied. For each unit there is an important objective listed which you have worked toward. Circle (%) or check (✓) the percentage of the behavioral objective you believed you achieved.

Unit: Sound Waves

Objective: The student will be able to define the nature of sound, list its characteristics and solve scientific problems relating to sound.

(Percent Achieved)

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

Unit: Harmonic Motion & Waves

Objective: The student will be able to demonstrate an understanding for properties of simple harmonic motion and waves, list types and characteristics of waves, and solve mathematical problems pertaining to waves.

(Percent Achieved)

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

APPENDIX A

Roanoke-Chowan Technical Institute

Opinionnaire

Course: Physics

Directions: Below is a list of instructional units on Physics you have studied. For each unit, rank each on the scale according to the degree which the unit has contributed to your successful achievement of the Physics Course.

(Circle Number)

Unit: Sound Waves

very little — a great deal

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

(Circle Number)

Unit: Harmonic Motion & Waves

very little — a great deal

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16