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ABSTRACT

The efficiency of the butterfly catastrophe model for describing and predicting performance changes in an educational setting was studied. Subjects were 455 introductory psychology students. Changes in performance on the first exam and three subsequent exams were examined, plus extra credit for participation in psychology experiments. The butterfly difference equation was tested using hierarchical stepwise regression. The model, which assumes nonlinear change, predicted performance more accurately than two linear alternatives. Where the goal was to predict performance at the end of the program, the butterfly model offered a 37.7 increase in utility. Larger positive changes in performance were observed for successive administrations of the course, indicating that the course was steadily improving. The degree to which the course was perceived as important for career goals (extrinsic instrumentality), was found to be a significant bifurcation variable. Women showed more favorable performance changes compared to men. The butterfly model described the motivational dynamics taking place in the classroom. The collective learning curves varied along four parameters: extrinsic motivation, intrinsic motivation, programmatic differences, and ability. Equations and explanations of the model, including applications for training evaluation, are included. (SW)

Butterfly Catastrophe Model of Motivation in Organizations: Evaluation of an Introductory Psychology Course

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RUNNING HEAD: Catastrophe Theory Evaluation

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Abstract

This report addresses the relative efficiency of the butterfly catastrophe model for describing and predicting performance dynamics in an educational situation. Subjects were 455 students in an introductory psychology course. Hypothesized control variables were: semesters college experience, prior courses in psychology and statistics (*a*); extrinsic instrumentality and sex (*b*); career plans in psychology (*c*); and administration of the course (*d*). Results indicated that the butterfly model (R^2 = .55 was more accurate than the linear alternatives (R^2 = .04 and .29. Significant effects were obtained for independent variables. With regard to sex related differences, women showed more favorable performance changes compared to men.

Butterfly Catastrophe Model of Motivation in Organizations: Evaluation of an Introductory Psychology Course

The purpose of this paper is to illustrate the evaluative properties of the butterfly catastrophe model for describing and predicting performance changes in a learning situation. The model is based on an assumption of nonlinear as opposed to linear change. While the core model invokes a modicum mathematical complexity not yet common in psychology, it nonetheless offers some compelling advantages: (1) separation of true behavior change from random drift, (2) separation of individual ability and motivation effects from programmatic variables, (3) separation of stable and unstable levels of performance, (4) a compact description of how variables in the process interrelate, and (5) an overall superior level of accuracy.

Any well-planned program evaluation should accomplish the first objective (Campbell & Stanley, 1969). The others are properties of the catastrophe model, which is elaborated in three steps. The first describes the general systems properties of catastrophe theory, highlighting the five-dimensional butterfly model. The second describes the butterfly catastrophe theory of motivation and performance dynamics in organizations, along with existing support for the theory. The third elaborates an application of the motivation theory to training evaluation. The empirical example involves beginner level training in an introductory psychology course, which serves as a controlled prototype for industrial training situations as well. Fundamental to the entire line of reasoning is the hypothesis that the butterfly model is a better descriptor of change than a comparable linear alternative.

Catastrophe Theory

Catastrophe theory is a general systems theory for describing and predicting discontinuous changes of events (Thom, 1975). It originated in differential topology. At its core is the theorem that all discontinuous changes may be described by one of seven elementary nonlinear models. (There are qualifications to this proposition that do not concern us here). The models are characterized by their level of behavioral complexity described, the number of control parameters required to effect the array of changes, and concommitantly the number of stable and unstable points involved. Numerous applications of the elementary catastrophe models are known in the physical, biological and social sciences (Cobb & Ragade, 1978; Poston & Stewart, 1978; Thompson, 1982; Zeeman, 1977). Of interest here is the butterfly catastrophe model and its applications to motivation in organizations (Guastello, 1981, 1984a, 1984b, 1985) and learning in laboratory settings (Baker & Frey, 1980; Frey & Sears, 1978) and training evaluation (Guastello, 1982).

The general properties of the butterfly model are described next, with a brief mention of the cusp and swallowtail models which are subsets of the butterfly. Third, the use of polynomial regression equations for evaluating a catastrophe theory hypotheses are explained. Further explications of modeling and evaluation concepts may be found in two recent psychology papers (Guastello, 1985; Stewart & Peregoy,

1983) plus other references mentioned above.

Butterfly Model

Surface. The butterfly catastrophe model describes three qualitative modes of behavior, and changes among them. Behaviors are depicted on a five-dimensional response surface. The modes represent not only qualitative behaviors, but also points of stability, and statistical density. The areas between the modes are regions of instability where few points fall. Figure 1 shows the most interesting three-dimensional sectioning of the butterfly model.

Behavior change is depicted by the path of a control point along the behavior surface (dotted line in Figure 1). As the control point follows a horizontal trajectory, behavior remains constant. When the control point reaches a fold line (cliff) behavior changes suddenly. Behavior may change between extreme modes, or between consecutive modes by slipping through a pocket in the surface. The pocket is the region of greatest instability, and in which behavior is most ambiguous. Taken together, the butterfly response surface is the set of points where

$$y^5 - dy^3 - cy^2 - by - a = 0. \qquad (1)$$

In Equation 1, y is a behavior measurement, and a, b, c, and d are control parameters.

Insert figure 1 here

Controls. Each control parameter has a unique function in the model. Asymmetry, a, governs the proximity of the control point to the manifold where the change mechanism occurs; it also measures the relative density between consecutive modes. Bifurcation, b, has a triggering effect. For low values, change is smooth and unstable. For higher values, change is sudden, but stability is obtained around the new mode.

While b governs change between the lower mode and the other two, the swallowtail, or second asymmetry parameter, c, governs change between the upper mode and the lower two. Finally, the butterfly, or second bifurcation parameter, d, determines whether the effects of b and c are coactive or interactive.

Bifurcation set. The bifurcation set shown in Figure 1 below the response surface is a four-dimensional map (or shadow) of the butterfly manifold. A two-dimensional section is shown, which corresponds to the surface section. It represents the critical points where change takes place, and is the set of points where the first derivative of the surface equation is a minimum:

$$5y^4 - 3dy^2 - 2cy - b = 0 \qquad (2)$$

Bifurcation sets in general serve the function of reducing entropy in a system by subdividing its area into zones of stability (Agu, 1983; Thompson, 1982).

Other cuspoids. The fold, cusp, and swallowtail catastrophe models should also be mentioned, as they are subsets of the butterfly model. The fold model describes change from one stable behavior state to an unstable state. The response surface is the set of points where:

$$y^2 - a = 0, \qquad (3)$$

where y and a are behavior and asymmetry as before. The cusp describes two stable behavior states and an unstable region between them:

$$y^3 - by - a = 0 \qquad (4)$$

where y, a, and b are behavior, asymmetry, and bifurcation respectively. The swallowtail model describes behavior changes among two stable and two unstable states. It is the set of points where

$$y^4 - cy^2 - by - a = 0, \qquad (5)$$

in which c is the swallowtail parameter (Poston & Stewart, 1978; Thom, 1975; Zeeman, 1977).

Statistical Evaluation.

The butterfly hypothesis is tested by means of the polynomial difference equation

$$\Delta z = \beta_0 + \beta_1 z_1^5 + \beta_2 z_1^4 + \beta_3 dz_1^3 + \beta_4 cz_1^2 + \beta_5 bz_1 + \beta_6 a, \qquad (6)$$

in which

$$Z = (y - \lambda) / s, \qquad (7)$$

where y is behavior, λ is the location parameter, s is the scale parameter, a, b, c, and d are control parameters, and $B_0 \ldots B_6$ are regression weights. The location parameter fixes a zero point on the behavior measure; it may be set equal to 0.00 or the lowest observed value may be used. The scale parameter denotes variability around a mode, rather than around a mean, but is pre-estimated by its ordinary least squares standard deviation. Measurements for control parameters would be similarly normalized before entry into the regression equation.

Hypothesis testing. The R^2 coefficient for Equation 6 represents the degree to which the data are described by the butterfly catastrophe model. One or more experimental independent variable may be hypothesized in each of the a, b, c, and d positions, and Equation 6 would be expanded accordingly. Simple correlations and tests on the individual terms in the model indicate the relative impact of the independent variable set.

The second term in the model, z_1^4, must be tested, although it does not appear in the mathematical surface equation. The size of its regression weight is dependent on the choice of λ ; $B_2 = 0.00$ when is estimated perfectly.

Two linear models are then constructed and their R^2 values compared with that of the butterfly equation:

$$\Delta y = \beta_0 + \beta_1 a + \beta_2 b + \beta_3 c + \beta_4 d, \tag{8}$$

and

$$y_2 = \beta_0 + \beta_1 y_1 + \beta_2 a + \beta_3 b + \beta_4 c + \beta_5 d. \tag{9}$$

If R^2 for Equation 6 is greater than R^2 for Equation 8, the butterfly model is said to be a better description of behavior change than the linear model. If R^2 for Equation 6 exceeds that of Equation 9, then the regression surface is more catastrophic than smooth, and is the best predictive model overall.

Similarly, for the fold, cusp, and swallowtail models:

$$\Delta z = \beta_0 + \beta_1 z_1^{2} + \beta_2 a, \quad (10)$$

$$\Delta z = \beta_0 + \beta_1 z_1^{3} + \beta_2 z_1^{2} + \beta_3 b z_1 + \beta_4 a, \quad (11)$$

and

$$\Delta z = \beta_0 + \beta_1 z_1^{4} + \beta_2 z_1^{3} + \beta_3 c z_1^{2} + \beta_4 b z_1 + \beta_5 a. \quad (12)$$

Linear models comparable to Equations 8 and 9 would be constructed for comparison.

Motivation in Organizations

Theory

Entropy. Entropy in the system is caused by a combination of exposures employees receive from the organization and their initial level of arousal prior to entering the organization. The force is particularly strong when the employee first joins the company. Policy changes within the company, new job assignments, and training programs are classes of events that can augment entropy in the employment experience.

Surface. The behavior surface is five-dimensional, and describes change among three stable modes of behavior. On the upper mode, subjects would show self-directed, internally committed behavior; high output and high quality work; innovation, which is partially based on prerequisite abilities, occurs at the extreme end of this subdivision; absenteeism would be virtually nil. There is a high disparity among subjects in intent to leave the organization, in that some subjects would harbor high intent to leave while others virtually none. There is thought to be no discernable difference in the work behavior between these two groups of subjects.

The middle equilibrium is thought to be characterized by externally motivated behavior at low levels of commitment. Innovation would not occur for high ability subjects. Quantity and quality of work would be good enough to get by. Absenteeism would occur at the major modal rate. Intent to leave is higher than in the upper mode overall; there should be lower disparity among subjects.

Persons at the lower mode leave the organization voluntarily or are fired for chronic absenteeism or poor performance. In organizations that do not have an organized absenteeism policy, chronic absentees are classified at this level. In extreme conditions of inequity there are strikes and riots, which are likely to be instigated by the erstwhile innovators from the upper mode. Turnover is the asymmetric reverse of organizational entry (Guastello, 1981, 1984a,1984b, 1985).

Controls. Control variables are ability (a), extrinsic motivation (b), intrinsic motivation (c), and organizational climate (d). Ability here denotes ability in the conventional sense plus any biodata items that might be used in a personnel selection scheme in place of ability. The motivation variables denote a wide range of specific motivational influences. In addition, any sex- or race-linked variable that is otherwise known as a moderator of ability would be a b-parameter variable.

Climate in the model consists of both subjective and objective variables (James & Jones, 1974; Jones & James, 1979; Heller, Guastello, & Aderman, 1982), and describes differences among gross types of organizations within type and differences among subgroups within an organization. Part of what is currently conceptualized as subjective climate would behave in the model as a c parameter, specifically those aspects that enhance or hinder intrinsic motivation. Butterfly parameter variables are those that govern the coaction of intrinsic and extrinsic motivation types, plus exposures that vary by organization or subunit rather than by individual employee (Guastello, 1981, 1984a, 1985). Empirical support has been found for several aspects of the butterfly model for motivation in organizations, and is discussed below.

Empirical Support

Turnover. A cusp subset model for turnover (Sheridan, 1980, 1985; Sheridan & Abelson, 1983) appears to have the highest predictive accuracy rate of any turnover study on record (84-86%), compared to others reported in a review by Hom and Hulin (1981). Relative control variables were job tension, commitment, and group cohesion for hospital staff samples.

Academic Performance. The academic performance application was designed around a counseling problem: Identify those students whose performance will not meet university requirements. The criterion was the change in relative performance as measured by Grade Point Average (GPA) from high school senior year to second semester college freshman status. Tested controls were: American College Test composite scores (*a*); academic orientation scores from Strong Campbell Interest Inventory (SCII; *b*); realistic, investigative, and enterprising theme scores (SCII; *c*); organizational climate (*d*) was replaced by a constant, 1. Statistical variations of the nonlinear butterfly model described performance considerably better (R^2 = .36 to .70) than the linear control hypotheses (R^2 = .02 to .09).

The hypothesized controls made only small contributions to the overall model (Guastello, 1984b, 1985).

Absenteeism. The third example was the evaluation of a change in a manufacturing company's policy for rewarding good attendance. Since there were no chronic absentees or turnover cases in the experimental sample, only two modes of absentee behavior were represented, close-to-none and the average rate. Data analysis did verify that the program change had the desired impace, and the nonlinear cusp model outperformed (R^2 = .58) the linear alternative (R^2 = .30) to a considerable degree (Guastello, 1984b).

The ramifications of the butterfly motivation model for training dynamics are considered next. General principles are followed by a specific problem, which is the evluation if a college level introductory psychology course.

Training Models

Structural Properties

Learning. Industrial and educational training are wholesale applications of learning theory. The catastrophe model for training evaluation is developed in two steps: the relationship between the cusp and learning curves, and an adaptation of butterfly motivation theory for training evaluation.

The typical learning curve plots performance over time, where the latter is usually calibrated in learning trials or blocks of trials. The equations for learning curves take the form:

$$\underline{P}_2 = \underline{k}\ (\underline{M} - \underline{P}_1) + \underline{P}_1, \qquad (13)$$

in which performance on a subsequent trial (P_2) is a function of maximum possible performance (M), previous performance (P_1) and an empirical value (k) which denotes the amount of inflection in the learning curve (Deese & Hulse, 1967). The $M - P_1$ element denotes asymptotic stability, which is a property of catastrophe models. The second mode of stability is the base rate of performance prior to the onset of the learning set.

A typical learning curve is depicted in Figure 2. Next, the curve is extended into negative time, showing no learning or performance during the time frames before the learning set. The resulting curve is a sigmoid. Stewart (1980) showed mathematically that sigmoids are cusp trajectories. That paper further illustrated the set of trajectories that comprise a butterfly surface.

Insert Figure 2 here

The reverse of the learning curve is an extinction curve. Two experimental reports involving rabbit eyelid conditioning illustrated that the inflection points for learning and extinction curves are different. Extinction curves are not merely the reverse path of the learning curve; additional extinction trials are needed to ensure nonemission of the behavior in question (Baker & Frey, 1980; Frey & Sears, 1978). Taken together the foregoing studies provide evidence that learning and extinction dynamics are at least cusp catastrophic in nature. The cusp is a subset of the butterfly model which is developed next.

Two-stage selection. The cusp model for two-stage personnel selection and training evaluation addressed the situation where performance is measured at two points in time, once just after entering the organization, and again after completion of the training program. In the case where all subjects partake of the same program, ability variables contribute to the asymmetry parameter; demographic variables could contribute to the bifurcation parameter, denoting differential impact (Guastello, 1982). For instance, Chisholm and Krishnakumar (1981) reported a training situation where bifurcation by sex did appear. When asked several questions regarding the value of a training device (a computer simulation), male responses were normally distributed, but female responses were bimodally split, which indicated a cusp-catastrophic distribution. Women in the sample were divided between those whose needs were met and those who were not so satisfied.

Differential impact by sex is not the only plausible contributor to parameter b. Differential motivation may also be relevant as prescribed by the general butterfly motivation theory. In cases where there is a training group and a control group or variations on the training program, the training variable (set) would be hypothesized as bifurcation parameters.

The cusp model for two-stage selection training evaluation circumvents a classic dilemma: how to reconcile the attrition cases. The model prescribes that they be retained in the sample, but given a time-2 performance score equal to the location parameter. The model thus describes not only selection and training efficiency, but turnover as well (Guastello, 1982).

Butterfly Hypothesis for Introductory Psychology

Surface. The hypothesized response surface describes change in relative performance on the first exam to relative performance on the sum of three subsequent exams plus accumulated extra credit points for participation in psychology experiments. The upper of three modes would reflect high test scores and many bonus points. The middle mode would reflect mediocre performance and fewer extra credit points. The lower mode students would be poor performers or those who withdrew after the first exam.

Control parameters. There were three hypothesized ability (a) variables: previous psychology courses taken, a statistics course previously or concurrently taken, and the number of semesters of college experience including the one in question. Forty-seven percent of the students in the 1983-4 academic year had taken general psychology in high school, and it was desirable to determine if the previous exposure impacted on their learning. Similarly, 15% of the students were previously or concurrently enrolled in a statistics course. The number of semesters of college experience (1 or 2 for the vast proportion which were freshmen) was hypothesized as a learning-to-learn ability variable.

There were two hypothesized bifurcation variables (b): sex differences and extrinsic instrumentality. The sex differences hypothesis was based on the Chisholm and Krishnakumar (1981) observations mentioned earlier that male-female reactions to a training set could be cusp-catastrophically distributed. Any sex-related differences in course preference or social adjustment would contribute to the significance of b_z, in the model, as would adverse impact as one commonly defines it (Guastello, 1982). The significance of the sex differences variable would not unilaterally imply adverse impact; one must also observe the direction of the relationship, sign of the empirical weight and net logic of the model before reaching a conclusion.

Extrinsic instrumentality was the degree to which students felt the introductory psychology course would benefit them with respect to a future job or graduate or professional school. This concept does not stray appreciably from the extrinsic motivation concept in the general theory (Guastello, 1981, 1984a, 1985). Instrumentality is a major component of the expectancy-utility theory of motivation (Dachler & Mobley, 1973; Vroom, 1964; Wahba & House, 1974). Utility, in turn, has been thought to function as a bifurcation variable in a sociopolitical catastrophe model for motivation to wage war (Morrow, 1983).

The variable hypothesized as the _c_ parameter was the student's stated intention to pursue a career in psychology. Those who were considering a career in psychology were thought to be more intrinsically motivated by the introductory course. Two possible butterfly dynamics might be observed: (1) The career motivated student might show larger positive performance changes, indicating a progressively increasing level of motivation. (2) The career-motivated students might be more homogenous in their motivation and performance output levels, in which case the non-career students would be the ones on the unstable regions of the surface.

The hypothesized butterfly parameter (*d*) was which one of four sessions of the course the student was a member. Each successive version was characterized by a larger class, a more experienced (but the same) instructor, plus unknown group dynamics. If the classroom technique was improving, then larger positive differences in performance would be observed in the later administrations. The opposite would be observed if the reverse were true.

It should be parenthetically noted that if one were to compare four different instructors, the hypothesis for *d* would be a bit different. Parameter *d* would be defined as a set of dummy coded variables denoting *k* instructors. The magnitude of the correlations between $d_k z_1^3$ and Δz would indicate the relative effectiveness of instructors' techniques.

Method

Setting and subjects. The setting was the PI's four Introductory Psychology sections from fall, 1983, spring, 1984, and fall, 1984. There were two sections in the latter semester. There were 455 subjects total. The text was *Basic Psychology* (Gleitman, 1983) and the compatible study guide (Jonides & Rozin, 1983).

Variables. There were four regular exams; some of the items were teacher written, some came from the study guide (Jonides & Rozin, 1983), and most came from the *Test Item File* that was compatible with the text (Jonides et al., 1983). An extra credit exam was also offered which covered material in the book's appendix on statistics. Students were also eligible to collect extra credit points for participation in psychology experiments operated through the Psychology Department. The time-1 criterion was performance on the first exam. The time-2 criterion was the sum of four regular exam scores plus all extra credit points. Regular exams and the extra credit exam were composed of four-option multiple choice items. Persons who withdrew after the first exam were scored 0.00 for the time-2 work not completed.

Students completed an intake data sheet which provided the following variables: prior psychology courses (range: 0 or 1), prior statistics course (0 or 1), semesters college experience (1 to 8), sex (1 if male), career plans in psychology (2 if yes, 1 if unsure, 0 otherwise), and extrinsic instrumentality. The latter variable was available for the fall, 1984 groups only; analyses concerning the variable were conducted accordingly. Group membership was an ordinal scale indicating sequential class number (1 to 4).

Analyses. The butterfly difference equation (6) was constructed and tested using hierarchical stepwise regression. The hierarchy prescribed that variables be entered from left to right as they appear in Equation 6; z_1^5 takes precedence over z_1^4, and variables within a parameter category (*a* or *b*) were subject to an empirically best criterion. The linear alternatives (Equations 8 and 9) were constructed and compared to the butterfly.

The course version and semesters experience variables, if significant for the linear models, would reflect any artifacts of scaling between the two groups' tests. These artifacts were corrected in the butterfly in which test variables are corrected for location and scale differences within verion of the course. All other variables were normalized across the entire sample. Values of λ for regular test scores were the number items that could have been gotten right by chance; λ was 0.00 for the extra credit test and experiment points.

The analyses described above were conducted twice. The first included all 455 subjects without use of the extrinsic instrumentality variable. The second included the 277 cases from groups 3 and 4, and used extrinsic instrumentality. As a final step, the critical points procedure was illustrated to determine zones of stability and instability.

Results

Reliability. The reliabilities of exams using Cronbach's alpha appear in Table 1 together with the number of test items and estimates of location.

Insert Table 1 Here

Four-group analyses. The butterfly difference equation accounted for 47% of its criterion variance (Table 2). The quintic term, which classifies the model as a butterfly was significant and course version, which together classify the model as a butterfly, were both significant at the .0001 level. Also significant were sex differences (b), prior statistics course (a) and semesters experience (a) at the .10 level.

The variable entry criterion of .10 was adopted to increase statistical power to compensate for some expected multicolinearity.

Insert Table 2 here

Greater positive changes in performance were observed for later administrations of the course. This finding is consistent with the hypothesis that the instructor improved over time. Women showed greater positive and negative performance differences than men; the net effect was larger positive net change compared to men. Students who had taken a statistics course did perform a little better than those who did not. Students in their first semester of college changed more abruptly in the positive direction than more experienced persons.

Since the hypothesized $\underline{c}$ variable was not significant, one last step was taken to improve the accuracy of the model. The parameter $\underline{c}$ was replaced by a constant 1.00. The variable z_1^2 was then entered into the model in the third position of the equation. Its weight was significant at the .0001 level. Some multicolinearity was observed between $\underline{z}_1^2$ and $\underline{z}_1^5$. The weight for sex differences was now nonsignificant, but it was retained in the model nonetheless. Significance levels of the other independent variables improved. $\underline{R}^2$ for the final model was .55.

The control difference model, by contrast, contained only one significant variable, semester of college experience ($\underline{R}^2$ = .04). The linear pre-post model contained two variables predicting time -2 performance: time -1 performance and semesters experience ($\underline{R}^2$ = .29). Overall, the accuracy afforded by the butterfly model was double that of the better linear alternative.

Analysis for groups 3 and 4. The analysis for the latter two groups in the study was conducted to test the extrinsic instrumentality hypothesis. Little variability was expected in d for three reasons: they were the two largest groups, were taught at close times of day (12 noon and 1 PM), and were most similar in instructor expertise than any other pair of classes studied. As a result the complexity of the model would be no greater than a swallowtail.

The hierarchical stepwise analysis showed that the best catastrophe model was indeed a swallowtail ($\underline{R}^2$ = .15). The career variable (c) was significant ($p < .001$) and indicated somewhat larger positive changes in performance for students planning a career in psychology compared to others. Extrinsic instrumentality and sex differences were also significant ($p < .10$). Women and persons perceiving low extrinsic instrumentality showed greatest positive changes (Table 3).

Insert Table 3 Here

The control difference model contained one significant variable, which was career plans ($\underline{R}^2$ = .03). The linear pre-post model contained two variables which were time-1 performance and career plans ($\underline{R}^2$ = .36). Taken together, the results showed that changes in performance were predicted five times as accurately with the swallowtail compared to the linear explanation. Changes in performance were more smooth than discontinuous, however. The greater proportion of smooth change could be caused by one or both of two conditions: cases remained in their respective zones of stability and did not change appreciably, and cases clustered around the swallowtail point. The swallowtail point is the zone of greatest instability, but is located in the region of the surface where this smooth portion meets the beginning of the manifold. An analysis of critical points can decipher what underlying circumstances resulted in catastrophic change for the four-group analysis but small change for the two-group analysis.

Analysis of critical points. The butterfly regression equation obtained from the four-group analysis (Table 2) was

$$\Delta z = (.0000918 \underline{z}_1^{\,5}) + (.0022816 \underline{z}_1^{\,3} * \text{version}) - (.12843 \underline{z}_1^{\,2}) - (.01468\, z_1 * \text{sex}) + (.09634 * \text{Statistics}) - (.15995 * \text{Semesters}) + .25241. \quad (14)$$

The set of critical points at which discontinuous changes are most likely to occur are, therefore, defined by the equation:

$$(.000459 * \underline{z}_1^{\,4}) + (.008448 * \underline{z}_1^{\,2} * \text{version}) - (.25686\, \underline{z}_1) - (.01468 * \text{Sex}) = 0 \pm 0.43, \quad (15)$$

where 0.43 is 0.5 standard errors of estimate obtained for Equation (14).

A condensed frequency distribution of scores for the four-group and two-group data sets at time-1 and time-2 appears in Table 4. Negative scores for Equation 15 indicate catastrophic change toward a stable higher level of performance. For the four groups together, large equal proportions of cases fell on a stable mode or unstable area. By contrast, the distribution of group 3 and 4 cases hovered around unstable areas with comparably smaller proportions in stable modes. As a result the latter distribution is more similar to a normal distribution. Normal distributions are subsets of the multimodal catastrophe distributions, located around the points of degenerate singularity, and away from the more interesting unfoldings (Cobb, 1981).

Insert Table 4 here

Values of Equation 15 were also calculated using time-2 performance scores. These values would forecast frequencies of stable and unstable fluctuations in the event the students took another psychology course with similar motivational dynamics operating. For the four groups together, the distribution of dynamics would be similar to that for introductory psychology, with the major exception that the negative shifting cases would be reduced. For groups 3 and 4, twice as many people would show positive stability, with an ever greater reduction of negative stability cases.

Discussion

The results indicated that performance dynamics within a learning set were best described by the butterfly catastrophe model, as hypothesized. The butterfly offered a 89.7% increase in accuracy over the better of the two linear alternatives. Where the goal is to predict performance at the end of the program, the butterfly model offered a 37.7% increase in utility, using a continuous definition. Data from several courses may be needed to illustrate the full butterfly model. Hypothesized control variables might not vary sufficiently in one particular group. Sampling distributions appear to vary with respect to proportions of cases lying in stable and unstable regions of the surface, according to the critical points analysis.

The hypothesized control variables were all significant in their respective positions in the model. Larger positive changes in performance were observed for successive administrations of the course, which indicated that the course was steadily improving. Future research questions should also address differences between instructors, or differences between training and nontraining groups. Such designs can be expected to result in larger butterfly effects compared to what was found here.

Students who were planning a career in psychology showed stronger performance improvements than others, but only for the latter two classes. Pilot analysis showed the opposite relationship for the first two classes. It is left to future investigation to determine what rule governs the direction of this relationship. The ad hoc explanation is that the first two classes of career subjects exhibited maximum output in both performance measures, rather than at the second time frame only. Why that would be true is still unknown.

Extrinsic instrumentality, which was the degree to which the course was perceived as important for career plans, was found to be a significant bifurcation variable. A sex-related bifurcation effect was also found. While its origins are curious and innexplained, the phenomenon itself was one of positive impact on women. The bifurcation effect noted by Chisholm & Krishnakumar (1981) appears to apply to more than computer simulations; it may also work in four of one group or another. Prior study of statistics and semesters college experiences contributed to the asymmetry parameter, which is generally defined as ability.

When the elements are considered together, the butterfly model describes the motivational dynamics taking place in the classroom. The collective learning curves vary along four parameters, which are generally defined as ability, extrinsic motivation, intrinsic motivation, and programmatic differences. The significance of the butterfly equation, critical points analysis, and comparisons with control models allow the investigator to evaluate whether stable intraindividual changes have taken place. It is often necessary, however, to compare several groups in an analysis for the full effect of the surface unfolding to be seen.

The results of this investigation give further support to the notions put forth by Baker and Frey (1980) and Frey and Sears (1978) that learning curves can be alternatively represented by catastrophe surface trajectories, and perhaps more accurately so. As a practical tool the catastrophe analysis can detect behavior change in the desired direction, separate true change from drift, and separate individual effects from program effects. The introductory psychology application, and training evaluation as a class of applications, give further support for the butterfly catastrophe model of motivation in organizations. The latter now appears promising for a wide range of situations. The proverbial door is wide open for theoretical and applied research.

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Author's Note

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Table 1

Estimates of Location and Reliability for Psychology Exams.

Test	Items	λ	α
First Semester Group (n = 67)			
1	40	10.00	.72
2	52	13.00	.77
3	64	16.00	.81
4	63	15.75	.81
Extra	20	0.00	.69
Second Semester Group (n = 111)			
1	60	15.00	.82
2	58	14.50	.76
3	60	15.00	.83
4	60	15.00	.78
Extra	20	0.00	.69
Third Semester, Two Groups (n = 277)			
1	60	15.00	.78
2	60	15.00	.78
3	60	15.00	.82
4	60	15.00	.78
Extra	20	0.00	.63

Table 2 Summary of Regression for Four-Group Analysis

Variable	F(model)	t	r	R^2
	Control difference			
Semesters	16.25[d]	-4.031[d]	-.21	.04
	Control prepost			
Test 1		11.98[d]	.50	.25
Semesters	78.45[d]	-4.40[d]	-.21	.29
	Butterfly catastrophe			
z_1^5		-16.40[d]	-.50	.25
Version * z_1^3		12.19[d]	.25	.45
Sex * z_1		-2.10[a]	-.16	.46
Statistics		2.32[a]	-.01	.46
Semesters	67.73[d]	-2.02[a]	-.10	.47
	Butterfly with C=1			
z_1^5		1.87[a]	-.50	.25
Version * z^3		15.44[d]	.25	.45
z_1^2		-8.40[d]	-.50	.53
z_1 * Sex		-1.51	-.16	.54
Statistics		2.18[b]	-.01	.54
Semesters	78.51[d]	-3.40[c]	-.10	.55

[a] $p < .10$ [b] $p < .05$ [c] $p < .01$ [d] $p < .0001$

Table 3. Summary of Regression for Two-Group Analyses

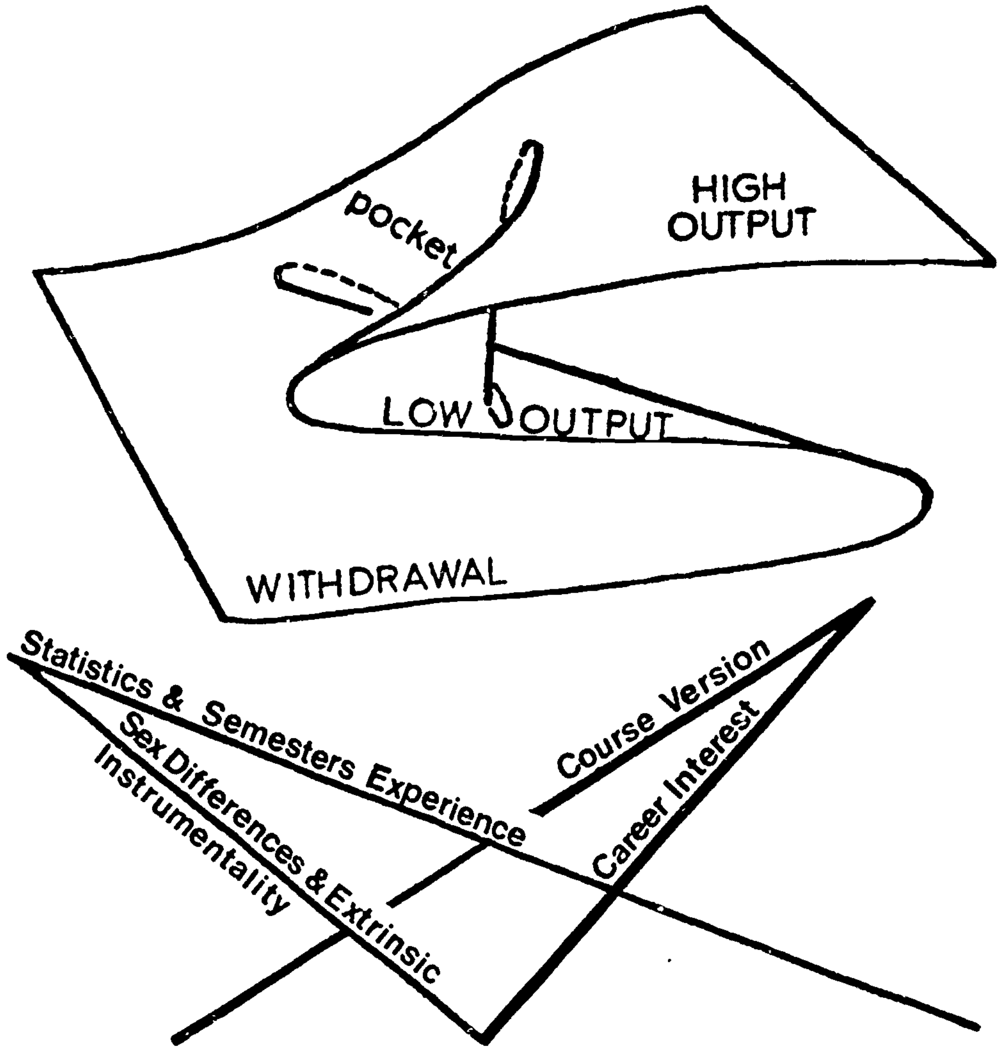
Variable	F(Model)	t	r	R^2
	Control difference			
Career	5.52[b]	2.349[b]	.16	.03
	Control Pre-post			
Test 1		10.87[d]	.59	.34
Career	63.06[d]	2.62[c]	.15	.36
	Swallowtail catastrophe			
Z_1^4		-4.13[e]	-.32	.10
Z_1^2 * Career		2.85[c]	.08	.12
Z_1 * Extrinsic		-1.92[a]	-.14	.13
Z_1 * Sex	9.09[d]	-1.87[a]	-.17	.15

[a] $p < .10$ [b] $p < .05$ [c] $p < .01$ [d] $p < .001$ [e] $p < .0001$

Table 4

Distributions of $\Delta^2 z/\Delta t^2$ at Time -1 and Time -2

$\Delta^2 z/\Delta t^2$ (St. Errors of Est.)		Pct All Four Groups	Pct Groups 3 & 4
Time 1			
-0.5 to -1.5	upper	46	10
-0.5 to +0.5		46	77
+0.5 to +1.5	lower	8	13
Time 2			
-0.5 to -1.5		45	20
-0.5 to +0.5		55	78
+0.5 to +1.5		0	2



BUTTERFLY

$$0 = y^5 - dy^3 - cy^2 - by - a$$

$$\Delta z = B_0 + B_1 z_1^5 + B_2 z_1^4 + B_3 d z_1^3 + B_4 c z_1^2 + B_5 b z_1 + B_6 a$$

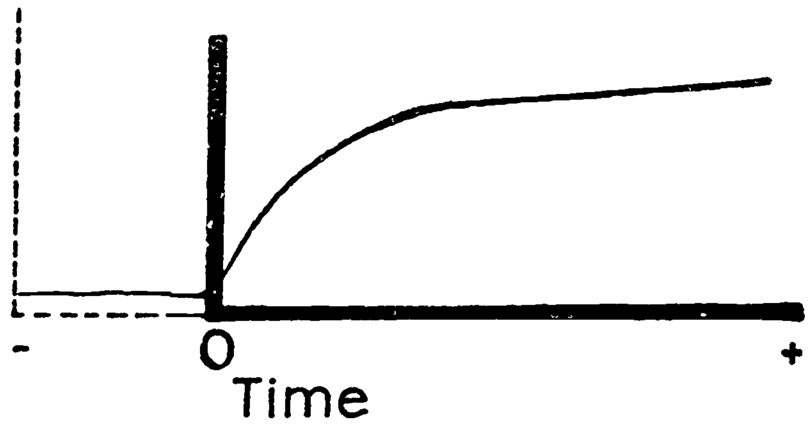

-
0
+
Time

Figure 1

Butterfly model obtained from the Introductory Psychology data.

Figure 2

Conversion of a learning curve into a sigmoid.