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Bibliographic note: *Chaos Network* was a start-up journal for a professional group, The Chaos Network, that specialized in a broad range of applications of nonlinear with a focal interest in organizational behavior. It operated from 1991 to 1996. The APA-style reference for this publication is:

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The essential results of this study were summarized in:

Guastello, S.J. (1995). *Chaos, catastrophe, and human affairs: Applications of nonlinear dynamics to work, organizations, and social evolution*. Mahwah, NJ: Lawrence Erlbaum.

Those interested in the role of the Chaos Network in the fabric of contemporary nonlinear science should see:

Guastello, S. J. (2009). Chaos as a psychological construct: Historical roots, principal findings, and current growth directions. *Nonlinear Dynamics, Psychology, and Life Sciences, 13,* 289-310.

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Does the CHAOS EXERCISE^{tm} Produce Chaotic Behavior?

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The Chaos Exercise^{tm} (Michaels, 1992) is a group dynamics simulation that was developed to provide its participants with an experience of chaotic change in the continuity of work flow. The players are organized into production groups and management groups; the "organization" is thus a complex system that exists within an environment that is generating spontaneous events that threaten the continuity or stability of production efforts. The game is well-known to the ***Chaos Network*** and I will, therefore, forego further elaboration of the game itself.[1] The purpose of this report is to test a hypothesis that is critical to the chaos paradigm of organizational development (Guastello, Dooley, & Goldstein, in press; Michaels, 1989): Does the Chaos Exercise actually produce chaotic behavior in the "production" groups?

Method

Participants. Human subjects were 6 industrial psychologists and 7 graduate students in psychology who were participating in a continuing education seminar on organizational research and practice. Seven participants were male and 6 were female.

Procedure. The "organization" in the exercise was configured into 3 production groups (4, 4, and 3 players) and one management group (3 players). Players began with a "work and resource" load of one production ball per group and 3 report balls per group. During the first round of the game, which lasted 10 minutes, a second production ball was introduced at the 6 minute mark. Other "random" events that were introduced into the first round were the power outage, interchange of personnel, and the tornado.

Between the first and second rounds of the game, a second set of report balls was distributed to each group. Management spent considerable time during the second round trying to sort the report balls to make a set, and the production groups experienced substantial downtime waiting for the report balls to be returned. Management was so overloaded (as determined by consensus of players during debriefing) that they usually forgot to yell "sale" when they completed a set of production balls. The facilitator needed to remind them to record their sales as well. The second round lasted 5 minutes, and a strike and a second power outage were introduced as the unplanned events.

Measurements. Players serving as production reporters were supplied with a clipboard, tally sheet, and stop watch. They followed the standard game instructions to record production units for 20-second time intervals. In principle, 30 data points should have been generated for each group during the first round, but actual quantities of points obtained were 23, 30, and 20 for Groups 1, 2 and 3, respectively. Group 3 recorded only one period of zero-production at times when it experienced two such periods consecutively. Group 1 did not have a clue as to why their time intervals did not total to 30.

Data for Round 2 should have been organized into 15 intervals per group. Actual recorded results showed 6, 11, and 7 entries for Groups 1, 2, and 3, respectively.

The primary measurement in this simulation was the the number of report balls generated by each group for each time interval. It became clear that this outcome measure was tainted with a form of error, but it was eventually determined not to be the type of measurement error that is normally assumed to exist in standard

[1] *Ed. note: The game is based on a group ball toss game in which a team tosses a number of balls in a circle at one time. The goal at each level is to have all members "touch" the ball at least once before returning to the team leader. When a ball complete the cycle it is a "product" ready to be sold. At the middle manager level, groups of balls start the cycle when production teams have completed a certain amount of products, and must complete the cycle before a "sale" is made. "Products" made, "sales," and "time between sales" are quantifiable data available for research such as this study. "Chaos" is introduced by the facilitator by introducing random events into exercise such as team absences, inventory fluctuations, etc.*

psychometric theory.[2] In the Chaos Exercise, measurement errors were epiphenomenal of the process itself, and were thus dependent on the true score and experimental context.

Results

Qualitative. Remarks from players during the game debriefing provide some insights to what took place during the administration of the Chaos Exercise. (1) The management group was the primary bottleneck that caused workers to wait idly until report balls were turned back. (2) Excessive effort was expended by the "organization" in the reporting of work. (3) Management did not consult with the worker groups when defining its intervention during the 10-minute lull between Rounds 1 and 2. (4) Time was lost training new workers as a result of the career change manipulation. (5) There was no incentive to keep practicing skills while waiting for management to return report balls. If they had done so, the groups would have accumulated a warehouse full of unsold work. (6) The system prevented workers from performing to capacity.

Analysis. Data from Rounds 1 and 2 (total of 96 points reported from 3 production groups), were analyzed separately, and the unequal time intervals were ignored. A simple nonlinear structural equation was tested[3] (Guastello, 1993a, 1993b) using nonlinear regression:

$$(1) z_2 - e^{(\theta_{z_1})} + C$$

where z_1 and z_2 were production values for two consecutive periods of time. C is an empirical constant (which needs to specified deliberately in nonlinear regression, in contrast to ordinary linear regression) and $e^{(\theta z1)}$ is a nonlinear regression weight.

Equation 1 is a simple nonlinear model with control parameters unknown; it gives a simple estimate of fractal dimension (Lyapunov) which indicates the complexity of the process, where dimensionality is calculated as e^{θ}. If θ is a positive number, a chaotic attractor is denoted. If is negative, a fixed point or limit cycle is denoted.

A linear regression model was also tested, and its R^2 coefficient and regression weights were compared with those obtained for nonlinear model ~~XXX~~ EQ 1 to determine which model produced the best fit to the actual data:

$$(2)\ Y_2 = B_0 + B_1 Y_1.$$

If the R^2 for a nonlinear model was greater than that obtained for the linear model, then the process would be accepted as a nonlinear process.

In Equation 1, the dependent measure is the number of production units corrected by location and scale parameters. Location was set equal to the trivial value 0.0 because many time period showed zero-production. Scale was the standard deviation of production across all groups and time periods. The dependent measure z

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[2] The standard assumption is that error scores are uncorrelated with true scores, errors are normally distributed, and errors have a mean of 0.0 (Lord & Novick, 1968). The foregoing supposition regarding the nature of measurement error in the Chaos Exercise could be readily assessed in the course of the nonlinear regression modeling for the production data. Low R^2 coefficients for all nonlinear models would be low if true psychometric noise were present. High R^2 coefficients would result if the error function were dependent on the true function and the hypothesized structural equation actually fit the data.

[3] More complicated functions based on bifurcations within the logistic map were tested as well, such as: $z_2 = \theta_1 e^{(\theta_2 z1 * x1)} + C$, $z_2 = \theta_1 X e^{(\theta_2 z1)} + C$, and $z_2 = \theta_1 e^{(\theta_2 z1)} + \theta_3 x$, where X was number of report balls per group in play, which was tested as a bifurcation variable. These approaches involved the analysis of both rounds of data together, and were abandoned when absurd results (negative R^2 were obtained for some of those functions. Had any of the bifurcation models been viable, the term B_2X would have been added to the linear comparison model.

was thus created by taking the raw number of production units and dividing through by the scale parameter.[4] No such transformations were needed for linear Equation 5, and the dependent measure is thus represented as Y.

An R^2 coefficient of .91 ($p < .001$, $N = 72$ data points) was obtained for the nonlinear model, producing Equation 3:

$$z_2 = e^{(0.361 z_1)} - 0.813$$

The dimension of the process was 1.43. The R^2 coefficient for the linear model was .18, which indicated a poorer fit compared to the nonlinear model.

Round 2 had the potential for introducing more chaos because of the larger number of report balls available for tossing to management. In practice, however, the Facilitator noticed (as did the players) that management became all the more confused and less timely about returning the report balls to the production teams. There appeared to be more waiting time, which was perforated by a shower of report balls from the production teams to management. In other words, production appeared more periodic in Round 2.

When Round 2 data were analyzed, an R^2 coefficient of .98 was obtained for nonlinear Equation 1, producing Equation 4:

$$z_2 = e^{(0.261 z_1)} - 0.948$$

The dimension of the process fell slightly to 1.30. The R^2 coefficient for the linear model was .01, which indicated no fit at all.

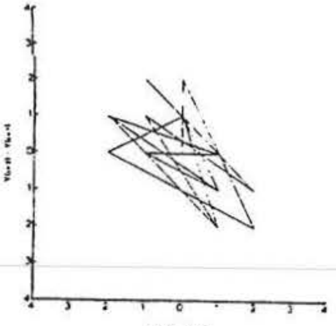

Fig 1: Phase portrait of raw data for Group 1 Round 1

Phase portraits. Figures 1 and 2 are phase portraits of the production data for Groups 1 and 2 during Round 1. The axes are calibrated in raw score units, such that the X axis is a change in performance over two consecutive interval of time, and the Y axis is a change in performance for the next consecutive pair of time interval. This method of composing a phase portrait is one of three basic variety described by Priesmeyer (1992; also see review of same in Guastello, 1993c).

The phase portrait for Group 3 during Round 1 just traced a diagonal from (-3,3) to (3, -3). If the extra zero-production time intervals had been correctly recorded, the trajectory would have traced a box around the diagonal with a cross intersecting at the origin.

Figure 3 shows the attractor basin for all groups combined for Rounds 1 and 2. Axes are calibrated in z -transformed units. Basins show three levels of density and illustrate the relative likelihood of finding any particular production rate pattern. The figures are based on Equations 3 and 4, which reflect functions that are optimally fitted to the data.

Discussion.

Because the exponent was positive in both rounds of the game, it is possible to conclude that the Chaos Exercise did produce chaos in the mathematical sense. Thus the results support the general efficacy of the chaos paradigm in organizational development. The dimensionality of the system was relatively low and, because it was less than 2.0, signified the possibility of one control parameter. The control parameter is probably linked to the management bottleneck, but future research needs to assess that possibility directly.

[4] The following estimates of the scale parameter were used: Round 1, Time 1, 1.23; Round 1, Time 2, 1.31; Round 2, Time 1, 2.69; Round 2, Time 2, 2.54.

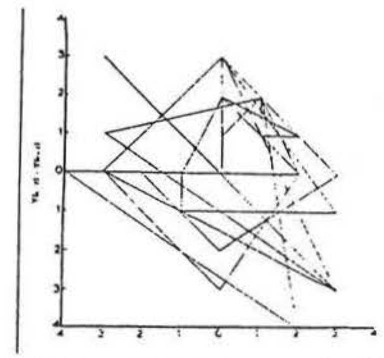

Fig 2: Phase portrait of raw data for Group 2 Round 1

The intervention between the two rounds of the game did not produce a change in the attractor's fractal dimension to any appreciable degree. The doubling of the number of report balls affected the scale parameter, rather than the complexity of the system. The statistical concept of scale has different origins than the use of the word "scale" in fractal geometry, but the meanings are relatively close insofar as what they imply about a system.

The nonlinear regression equation worked as expected when applied to Chaos Exercise data. The group behavior was theoretically chaotic. The consistency between expected and obtained results supported the efficacy of the nonlinear regression procedure for the assessment of chaotic processes. More importantly, however, nonlinear regression tested a theoretically driven hypothesis about chaotic behavior, which is something that cannot be done by merely plotting a good-looking phase portrait. The relationship among nonlinear regression results, the phase portrait, and data is anologous to the relationship among statistical tests, and graphs of data in conventional experiments: The graph displays a relationship but does not differentiate the trend from random noise.

The attractors represented in the phase portraits of both the raw data and derived functions also appear chaotic. At the present time there is no interpretation of what those intriguing geometries imply. It is plausible, however, that different configurations of management and production groups, group size, and countless other variables will eventually be found to explain why particular geometries are likely to occur.

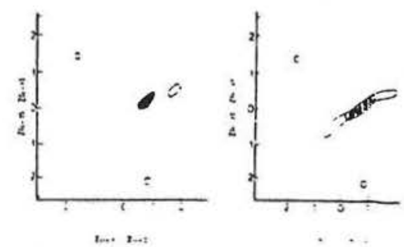

Fig. 3 Phase portrait for all groups based on nonlinear regression function obtained for Round 1 (left) and Round 2 (right).

Finally, the measurement errors associated with production reporting and time intervals was not the usual form of psychometric error, as denoted by the particularly high $R\{2\}$ coefficient for the nonlinear model. The results further suggest that those measurement anomalies are epiphenomenal of the group production process, but further research efforts should attempt to separate actual dynamics from the reporting of same.

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