The Systems Analysis of Learning Environments

Donald Kingsbury

Let me be very radical and suggest that subject mastery and the designing of environments which catalyze the learning of a subject are distinctly separate skills. I want to see people employed by schools who are crack designers of learning environments, who work in cooperation with the subject master to produce the most effective media for transmitting the abilities of the subject master. In other words, I want systems analysis methods to be applied to our schools.

Let's not get frightened by this term "systems analysis." It is just a method of allowing *you* to engineer an environment to do what *you* want it to do by adapting the same methods that were used to design steam engines and cars and antibiotics and computers and poison gas so successfully. If you set up the specifications that your school be structured to produce dynamic, articulate, self-motivated, intelligent, creative students, then systems analysis will create that school for you — providing you can pay for and amortize the development costs. The goals are yours, systems analysis is only a tool for achieving your goals — and not the only tool.

It works this way. First you define the problem in detail, *in operational terms*. Just this involves months of work. You have to know explicitly what kinds of students you want at a much deeper level than current practice. No vague wishy-washy verbal goals will serve your systems analyst as a target. Specifying a "dynamic student" is useless to him unless he has an operational method for consistently distinguishing between the "dynamic" and "non-dynamic" characteristics of students. Specifying that you want a student who can solve calculus problems is useless unless you have an operational method for differentiating between people who can solve calculus problems and those who cannot. The design specifications for your learning environment must be such that the systems analyst can decide whether his design has met or failed to meet specifications.

Second, the analyst requires a knowledge of the learning population, particularly of the distribution among the population of all the pre-abilities relevant to the subject being taught. A list of last year's marks will not even begin to serve this purpose. If no information is available or obtainable about pre-abilities, the analyst will be forced to make assumptions about them but won't get upset when his assumptions prove false.

The next thing our systems analyst needs is a learning hypothesis. It doesn't have to be correct. If it is wrong he'll find out as soon as he tries to build something, and his failures will indicate the changes that have to be made in the hypothesis. If he does not have a hypothesis he will rely on Authority which will mean that he will do What Has Always Been Done. None of us needs a systems analyst to tell us how to be conservative, therefore if yours doesn't have a solid learning hypothesis — fire him.

With this background, the analysts and the subject masters design a *pilot* project and carry it out. Predictions of design effectiveness must be made. During the pilot runs the analyst conducts *detailed but selective* observations of the students as they are actually learning, and these observations are compared with the predictions. When learning behavior and predicted behavior don't match, design revisions are necessary. For instance, if a particular art lesson, designed to generate original work from the students, produced only copying behavior, the design would have failed. In such cases better applications of the learning hypothesis may be in order, perhaps revisions of the hypothesis are required, and finally, if all else has failed, the team will have to ask for changes in the specifications.

Once the pilot project meets the specifications, it can be delivered to the "production" staff who can implement it in the expectation that the package will have few defects left. Normal production problems will, of course, arise.

This may sound like routine procedure. It is not. Production rather than developmental staff do the design work at present and have neither the resources nor the time nor the skills to do an adequate design job even when they are excellent teachers. They must work with production, rather than pilot, classes. Specifications are seldom made explicit and, when they are, seldom meet operational criteria. Knowledge of the target population is vacuous, and the learning hypotheses available to them are usually primitive. At McGill, where I teach, I know of *no* single example of a course which has been designed with even *minimal* attention to standard engineering design practices. My estimate is that proper environmental design procedures would routinely, and at lower cost, produce students of a quality which we consider exceptional today.

A Learning Hypothesis

The most sophisticated learning hypothesis available to us today is a cybernetic one based on the engineer's definition of control, and the psychologist's and physiologist's work with the association of stimuli and behavior, rather than the Skinnerian 'reinforcement' theory which has had an undeserved popularity.

The critical concept is the *control* of *associations.*

We use a simplified model of a person as a collection of units each of which *outputs* behaviors such as throwing a ball, thinking about hell, having a bath, or deciding to pay a bill and each of which *inputs* stimuli such as sounds, pictures, smells, or abstract representations of sounds, pictures, smells, as well as the behavior from other units. For instance, a thought about a cheese cake may input into a unit which outputs decisions about buying food. We assume that simultaneous input-output pairs become increasingly associated according to probability laws I don't want to go into here.

Naturally if one input is becoming more closely associated with a given output, it must be *dis*associating itself with other outputs. This is the process we call learning. "Stability" or "non-learning" states are often reached in which associations and dis-associations cancel. In such a state a human will tell you that his environment is predictable or that he is in a rut. Learning will be induced again upon the introduction of a "spice" which has been called "variety" by the sages. The human being then readjusts his behavior until he reaches a new level of stability. This state may be more sophisticated — contain a larger spectrum of abilities — than the old state, as in the child who has completed a problem he never saw before, or it may be temporary as in the student who got a first class on the final by studying the night before, or it may be a behavior degeneration as in the child who has been overwhelmed.

Defining the class of associations between stimuli and behaviors which we wish to create is one of the most difficult jobs to perform for any given course. The earliest adequate statement of this problem was made by Gilbert who laid out procedures for producing what he called a behavior prescription as an essential stage in every course design. In general we can say that the best solution is the *minimal* number of associations which will generate the desired behavior range. (Different sets of associations may produce the same behaviors, but one may be much more difficult to teach than the other. Some sets of associations are so cumbersome that the person owning them can't think adequately whenever even trivial modifications in the stimulating environment are made.)

It is not enough to know the desired set of associations. If the associations don't happen, they won't be learned. For instance, we can't expect students to become verbally articulate if we only teach them in environments where speaking is reduced to the level of one minute per hour per student. We must *control* the frequency with which the desired association occurs, in this case, thoughts and speaking behavior.

What do we mean by *control?* We adopt the engineer's definition.

First, control implies that we are controlling something. This is always the output of some system, the direction of a boat, the amount of money in an economy, the motion of an arm, the shape of a mental image, the amplitude of an emotion. The system in which we are interested outputs association pairs.

Second, control implies a feedback loop. We must (1) have a comparator which measures the *real output* of the system, knows the *desired output* of the system, generates the difference of the real output and the desired output as a signal called the *error,* (2) have a controller which uses the error to apply *correction strategies* to the system in such a way that the error tends to vanish.

Control by no means implies that it is the student who is controlled. The control loop may be, and often is, entirely internal. In essence what we mean by a "highly motivated, independent" person is someone who contains *within himself* a wealth of control loops, many of them acquired, some of them built in.

This hypothesis which sees learning and teaching as the control of association pairs gives us a viewpoint from which to examine all courses, schools, and educational programmes. It won't give us information about what we should teach but it will give us information about how effectively we are teaching.

Some Learning Control Problems

Many of us have taken lectures which almost immediately lost us. We could take notes but only the odd snatch here and there meant anything. I overheard a student coming out of the Faculty Course lecture the other day. She asked her friend, "What did he say?" Her friend replied, "I haven't got a clue — but I've got four pages of notes." "I've got six pages of notes." And they went off down the hall together.

Such situations occur because of a lack of essential feedback loops. The lecturer has a concept in his mind. His goal is to duplicate this concept in the student's mind. To do this you need a feedback loop which compares the concept in the student's mind with the concept in the lecturer's mind and which delivers some sort of correction strategy when a mismatch is happening. For effective learning the lag time of the feedback must be very short.

That it is almost impossible to set up a functioning feedback system during a lecture means that any learning environment which is making a maximal usage of the student's time will not place any major emphasis on lecturing as a teaching strategy.

Mager, Kaplan and others have experimented with what they call "student controlled instruction." This method was used more as a device to study learning than as a serious proposal for a learning environment but gives some ideas about what happens when control loops are deliberately introduced into the student-teacher relationship. The rules of "student controlled instruction" demand that many of the comparator functions of control be placed in the student's hand. The student chooses the goal. The teacher generates stategies which he thinks will cause the student to realize the goal. The student takes over the function of determining whether or not he understands, i.e. he must stop the teacher whenever he feels that he is not learning, can ask the teacher to develop correction strategies, or take a different viewpoint, generalize, or give examples, or he can just ask the teacher to stop while he figures out something. He can at anytime redefine the goal of the learning session. The teacher obeys the student.

These experiments have been done with small classes but the methods are not restricted to small classes and possible adaptations of them do not require a small student-to-staff ratio. Quite remarkable collapses of learning time have been demonstrated during learning under "student control" even with primitive correction strategies. Such environments show huge promise. Study situations where control functions are defined and carefully distributed among students and teacher can probably be designed to be more effective and cheaper vehicles for learning than mass lectures. Teachers will find themselves more in the role of master controllers than in the role of "presenters of material," more as overseers of study programs than as animated tape recorders.

A critical control problem involves scheduling. At present material is presented on a *time* schedule. The goal of such a schedule is set up so that a time is associated with each piece of material — so much must be got through by the end of the hour, by Christmas, before the examinations. The error signal, the difference between real and ideal presentation time, causes the teacher to speed up or slow down. Since this control system has nothing to do with learning, and does not monitor learning, the student as often as not gets wiped out.

A proper schedule would set up its goal in terms of minimal levels of *student competence,* not in terms of time. The comparator would measure student competence and would only allow new material to be introduced to the student when such competence criteria had been met. The way to *create* dull, stupid people out of bright intelligent children is to go on to the new material before they have achieved competence in the old.

Subject promotion rather than promotion by year is a small step in the right direction but still a pitifully inadequate solution. Eventually courses will have to be abandoned altogether to be replaced by short term (a few days to a few weeks) contracts which the school and student make together. Ideally, the "contracts" will be carefully designed and tested information/skill packages. They will be technological refinements of the old Dalton and Winnetka Plans — sophisticated and updated for the electronic age.

The logistic problem of setting up such a system — getting students, staff, facilities, and material together at the right time and keeping track of the result — is enormous. Large educational enterprises would have to enlist the services of a computer. Smaller schools have other alternatives. In the early '60's, an ingenious scheme was adopted by the Maple Park Grammar School, Oregon. The first six years of school were divided into twenty sections, sixteen of them defining basic learning areas. A student could enter such a basic section on any Monday and graduate from it on any Friday of the week in which he had achieved competence. Every fifth section was an enrichment routine — projects, readings, and the like — which students only left after reaching a specified stage — to keep them *au courant* with the rest of the world.

Scheduling in the direction of controlling competence level instead of controlling pace should bring dramatic improvements in student motivation and learning, and incidentally accelerate the learning pace.

The applications of control theory to learning environments are limitless. For instance, in causing a student to associate some input with some output behavior, a mediating stimulus, called a "clue," is generally necessary to drive the desired response. (The English word "dog" or a picture of a dog can act as a clue when we are trying to associate the word "chien" with the dog concept.) The rate at which clues are withdrawn has a critical effect upon learning time — if the clues disappear too rapidly so does the desired response; if the clues persist too long, the clue-response association is reinforced at the expense of the wanted association. The rate of clue withdrawal is thus a control problem.

The lag-time between the making of a mistake, the identification of the mistake, and the application of a correction strategy has an obviously vital effect upon learning times. A systems analyst must look at the learning control loops, measure the lag times and create environments where these lag times are minimal.

Moore's Talking Typewriter is a suberb example of what can be done to collapse learning times by shortening control loop lags. The typewriter speaks and the student tries to type what was said. He is *immediately* informed when he has made a spelling mistake because the key won't work. He then hunts for the right key. Thus only the correct spelling is associated with the sound, and in less time than in any other system. Lag time could be even further reduced by projecting a keyboard on a screen after every mistake indicating the correct key. The talking typewriter allows second graders to handle seventh grade vocabulary without stress because it collapses seven years of training into two by shortening the involved lag times.

Other applications of control theory involve the *rapid* teaching of language comprehension and speaking, correction of term papers, the teaching of articulateness, testing and study programs.

Conclusion

A breakthrough in the creation of learning environments will occur once we have a profession of people who can:

1. Make explicit the covert and overt behaviors we wish our students to retain from the course;
2. Assemble these behaviors into a minimal number of input-output associations which will produce the desired range of behavior;
3. Develop *control* stategies which cause the associations to happen. The control loops must have minimal lag times and as many of the control functions as possible should be the responsibility of the student.

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