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ABSTRACT

A study was undertaken to examine the practicality of formulating efficient teaching strategies by deriving them from simulations of learner characteristics. Thirty interdisciplinary concepts were introduced as guidelines for learning efficiency, and three principle requirements for learning efficiency were derived: (1) educational materials should be matched with the sensory input/data-processing characteristics of the learner; (2) students should determine their own pace; and (3) adequate motivation should be ensured. The simulations were introduced at regional medical meetings, and the reactions of 846 physicians were solicited. The resulting recommendations to improve training programs included the use of more on-the-job-training, the use of more simulations and games, and more student control over the pace of learning. (EMH)

TREADING THE TROUBLED WATERS OF TRAINING: SOME GUIDELINES FOR IMPROVING LEARNING EFFICIENCY

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ABSTRACT

The role of learning as a tool for enhancing human efficiency and survival characteristics is examined. The advantages of using simulations in general, and simulated patients in particular, as a means of improving learning efficiency is discussed. Thirty important concepts based on research findings from the areas of mathematics, biophysics, physiology, information theory, cybernetics, psychophysics, physical psychology, neurosurgery, brain cell function research, artificial intelligence, communication and media are presented. These concepts provide solid guidance for individuals interested in promoting learning efficiency. Furthermore, these raise important issues that must be satisfactorily resolved by any theory which purports to explain how humans learn.

Based on these premises it is suggested that the three principal requirements which are necessary for the optimal packaging of information for learning efficiency are (1) matching educational materials to the sensory-input/data-processing characteristics and other personal needs of the learner, (2) enabling each student to control his own learning pace and (3) assuring adequate learner motivation.

Simulations constructed in accord with the above concepts of information packaging were tested at eight national and regional medical meetings.** Reactions from 846 physicians and other health professionals were solicited. More than ninety percent found them interesting, instructive, challenging, useful and thought that they "rang true."

It is concluded that training institutions could significantly improve learning efficiency by (1) providing more "on-the-*real*-job" experiences, (2) incorporating wider use of simulations and games that realistically mirror important situations and (3) allowing each student to control the pace of his own training insofar as possible.

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INTRODUCTION

At a recent simulation conference, one speaker began his address with the following observation:[1]

> Phaedrus, in the year 8 A.D., wrote: "Things are not always what they seem." Gilbert (of Gilbert and Sullivan) wrote: "Things are seldom what they seem." Longfellow, not believing in half-way measures, wrote: "And things are not what they seem."

However, a long-standing, intimate involvement with simulation and applied learning research suggests instead that "things are never what they seem."

Although why this is so remains a puzzlement, there is mounting evidence, and increasing agreement that each one of us is unique in a quite "physical" sense, lives in his own unique world, and looks at life in his own unique way. After intensive study of "paleoneurology and the evolution of mind," Jerison suggests that the "work of the brain is to create a model of a possible world rather than to record and transmit to the mind a world that is metaphysically true."[2] Self-deception may be the rule, not the exception.

Also, it is not clear whether "similarity" or "difference" is the more important concept. However, if too many differences exist in any situation under examination, it is easy to become confused about the relative importance of different aspects and learning is thereby impeded. So for our purposes similarity is considered the most important and within contexts that are predominantly similar we concern ourselves with differences that are "important" in a quite personal but generally replicable sense. All formal educational endeavors, for example, are at base quite similar. A colleague of mine has even suggested that there are no important differences between schools that provide training for professionals and kindergartens. True, the students are bigger and the talk is about different things, but they still inhabit classrooms where they are expected to remain seated, are occasionally reminded to keep quiet, have someone up front talking at them and smiling at them, and they even participate in "show and tell."

Finally, we rely heavily on the weight of evidence collected so far which strongly suggests that there are considerably more similarities than differences between human beings and anything else we can accept as living organisms.[3] Man possesses few if any "physical" mechanisms that are unique, even though the particular type of genetic mix and the level of complexity is unique, of course.*

In the sections that follow, we will first consider some of the advantages of using simulated ~~patients~~ instead of real patients. We will then briefly examine some of the evidence regarding man's built-in continuing drive for greater efficiency and the role of learning as a tool for improving both individual and collective efficiency. Next, we will present some of the conceptual results of our investigation with respect to how people learn, list the three principal requirements for increasing learning efficiency, and then discuss the results of administering simulations constructed in accord with specific information-packaging techniques. Finally, we will offer some guidelines for individuals interested in helping their students learn more efficiently.

*Eric Lenneberg argues that the "neural coordinates of language capacities are a propensity for certain activity patterns in the human brain," rather than assemblies of components that are structurally unique to man. (See reference #67, p. 363.)

ON USING REAL PATIENTS

I suppose it's fair to ask, "Why use simulated patients instead of real ones?" Fortunately, or unfortunately, depending upon one's views on such matters, the supply of "guinea pig" patients who are willing to submit to medical procedures designed principally for the purposes of training students is dwindling.(4) During the last decade, for instance, the number of students enrolled in American medical schools has increased by 70%(5) while the average daily census of patients in American hospitals has decreased by 20%(6).

Traditionally, a plentiful supply of indigent patients has served training needs; but as we inch closer to some form of universal health care coverage, such patients will no longer find it necessary to submit to what some refer to as "fumble finger medicine" in order to be eligible to receive any medical care at all. Although such care might possibly be considered appropriate by some for one's mother-in-law, business competitors, etc., in general, everyone, paying or not, prefers for students to "look-but-not-touch."

Compounding the problem of a diminishing supply of captive patients for teaching is the growing public demand for greater competence on the part of doctors. The soaring rates for malpractice insurance reflect well the fact that yesterday's methods are not considered adequate by today's patients.(7) In the past, unfortunate medical outcomes were often considered to be "acts of God." Nowadays, however, they are more likely to be attributed to human incompetence. The disgruntled patient now seems more inclined to consult a lawyer than a minister. Approximately one doctor out of eight is currently being sued for malpractice.(8) One wonders whether Hipprocrates would be allowed to continue in practice these days.*

Regardless of whether or not one prefers to believe that the malpractice situation is merely a reflection of an oversupply of attorneys, the fact remains that most medical specialty societies and an increasing number of states are requiring that doctors more diligently pursue their avowed quest for greater competence by formal enrollment for continuing education. As a result, the burden of providing the necessary training falls upon the shoulders of the same training institutions that are already finding it increasingly difficult to secure enough patients with the "right" diseases to provide the spectrum of training experiences now being demanded by practicing physicians and considered essential for students. It is thus becoming more attractive to utilize simulated patients.

Furthermore, some of the most poigiant lessons of life are learned as a direct result of one's errors. (Pounding nails, for example, can be most instructive.) However, in medical training one cannot tolerate errors -

*Rubsamen (see reference #7) suggests that the more able physician attracts more than his share of seriously ill patients, often with unrealistic expectations, and consequently is exposed to greater malpractice risk than are his less competent colleagues.

at least not with real patients. Simulated patients are amazingly resilient in this regard and can offer the added dimension of learning by trial-and-error. For example, a physician might be hesitant to utilize a personally untried (but perhaps appealing) therapeutic regimen on a real patient. However, it can be safely employed on a simulated patient. If, as a result, the "patient" dies or suffers some other unfortunate outcome, the physician usually has no difficulty remembering this situation later on when similar circumstances are encountered with a real patient. If it does work well, however, this bit of expertise can replace or modify other less effective techniques.

In addition, the nature of simulation feedback is more conducive to efficient learning. With real patients it is quite common to receive little or no direct feedback at all. McGuire has suggested that, "In real life it is often the case that only equivocal results are indirectly provided after long delay."(9) Simulated patients, on the other hand, can provide the prompt, specific, unambigious information necessary for efficient learning.

Also, simulated patients are an amazingly hardy and congenial bunch. They have been repeatedly mistreated by all manner of students. They have been allowed to develop unnecessary complications, to die, to commit suicide, etc., and yet, never has one simulated patient ever sued anybody for anything.* In these days of increasing awards for malpractice judgments, this aspect may well become of more than trivial importance.

Finally, it should be noted that simulated patients cannot completely assume the place of real patients for all training purposes and vice versa. The experiences provided are not the same. However, by using simulated patients wherever and whenever possible and appropriate, we can perhaps utilize more judiciously those patients who do graciously consent to serve our training needs.

SIMULATION AND LEARNING EFFICIENCY

Once agreement is reached that simulated patients should be utilized insofar as possible, the next question concerns how one should go about this. Certainly not all simulations are created educationally equal. What is it that is important and what isn't? The following discussion indicates where we are in our thinking in this regard at this time.

Toward a Theory of Learning

Simulations constitute one of the techniques for promoting learning. Hence it seemed appropriate to review what has been discovered about how people learn. This proved to be somewhat unsatisfying. Somehow most of the studies reported in the literature seemed to be concerned with what was going on around the learners (conditions of learning, "open vs. closed" classroom arrangements, "universities-without-walls," etc.) or with highly-speicifc,

*The mishandling of one particular simulated patient does finally result in receipt of a letter from the "patient's" lawyer advising that a malpractice suit has been filed. Simulations should be realistic, of course.

difficult-to-generalize learning of the stimulus-response variety (SR, SOR, etc.) or with "global" notions about learning methods supported by test results of an equivocal nature (Gestalt theory, "Renaissance man" considerations, etc.).*

As Gagné and Gephart concluded at the close of an national symposium on learning research:

> Perhaps the most general impression to be obtained from this stimulating conference is to the effect that there is an exciting, complex, and rather long road to traverse in proceeding from the learning of the laboratory to the learning of the classroom. Another suggestion to be gleaned from these interchanges is the need for alterations in ways of approaching the problem of learning, not only in the laboratory, but also in the classroom, if progress toward the goal of educational improvement is to be made.(10) (our emphasis)

As near as we could tell, most anything would work somewhere, sometime, under some circumstances, with some learners and some teachers; but dependable generalizations were few and far between, much like the current placebo research in medicine. In a sense, things haven't changed all that much since shortly after the turn of the century when John Dewey recommended "learning by experiencing."(11)

Learning and Efficiency

In an effort to acquire a better understanding of the connection between learning and "reality," we decided to make a fresh start. Following Einstein's example we chose a simple hypothesis and looked for evidences of invariance. Our beginning conjecture was this: Learning results in "structural" changes to the brain. We then looked for "hard" evidence which would support, refute, and modify our initial premise.

It was eventually noticed that energy efficiency seems to offer one of the most common invariances human beings experience.(12) Life abounds with examples of the effects of efficiency differences between species. The red bread mould, for example, is able to accomplish very little compared to other forms of life because it cannot efficiently utilize food sources; it must produce its replacement protein from scratch instead of from the amino acid building blocks that can be more efficiently utilized by carnivores.(13) Similarly, when adequate amounts of some essential substance, say histadine, are provided by diet for two strains of bacteria, one of which differs only in that its members cannot produce their own histadine, within fifty generations or less the ones which must obtain this ingredient from dietary sources will eventually replace their less efficient kin who are obliged to produce their own from scratch.

*Unfortunately, most classroom learning research reports which terminate with such statements as "Thus, group A learned more thangroup B" seem to fit this category.

Zemenhoff and Eichhorn have conducted a number of key studies in this regard.(14) In a typical experiment, back-mutants of bacteria from the same parental stock (Bacillus subtilis) were used to produce two different strains. Members of one strain produced their own histadine from scratch (his+), whereas the members of the other strain (his-) could not do so and had to obtain this from their diet. The two strains were subsequently allowed to compete in an environment that contained 0.32 millimolar L-histadine in addition to the usual nutrients. As shown in Figure 1, within thirty-six generations less than one bacterium in ten thousand could produce its own histadine. Similarly, with indole producers versus non-producers, the less efficient soon disappear.

Also, note that within twelve generations, the tryptophan non-producers (try-) completely disappeared in competition with anthranilate non-producers (anth-) when the environment contained the usual nutrients plus 0.25 millimolar L-tryptophan. This demonstrates that even for strains that require the same essential nutrient, the ones which manufacture fewer intermediates (and are thus more efficient) enjoy a strong selective advantage.

These are hardly surprising results. The more energy that is spent on organism-maintenance functions, the less that remains for more outgoing activities. Language has provided humans with a superb tool for sharing efficiency insights across time and distance, thereby enabling man to become the most efficient specie on earth.

When one observes life in this way it is possible to discern a fundamental characteristic of learning, namely, that it is the purposeful means of improving efficiency. Accordingly, the principal role of learning is that of reducing "local" entropy, or equivalently, of maximizing applied information.* It follows, then, that the most efficient learning process is the one in which the learner is able to assimilate the requisite learning with consumption of the minimum possible amount of time-energy. Furthermore, because learning is a natural process in which almost all earthly creatures are engaged almost all the time, it is reasonable to expect that the key mechanisms of learning are widely shared by all species of life. Furthermore, any mechanism that is so common must be relatively simple or it could not be widely dispersed among species of varying degrees of complexity. Even one-cell "animals" can be "taught."(16)

Some Key Concepts on Learning Mechanisms

Research results from many different disciplinary areas have contributed key pieces to the solution of the overall puzzle we must solve if we are to design educational experiences which guarantee that more efficient learning will occur. Important parts are still missing: the physical mechanisms of control processes, of "thinking," of memory deposition, of recall, and the mathematical basis of learning, to mention but a few. Unfortunately, we do not have sufficient time to review the many concepts which form the basic mosaic of the theory as it has developed thus far. However, what has been discovered so far does provide solid guidance. Table 1 lists some of the key concepts which have guided our thinking. The order in which they appear does not reflect anything of particular significance.

*"Information" is mathematically equal and opposite to "entropy."(15)

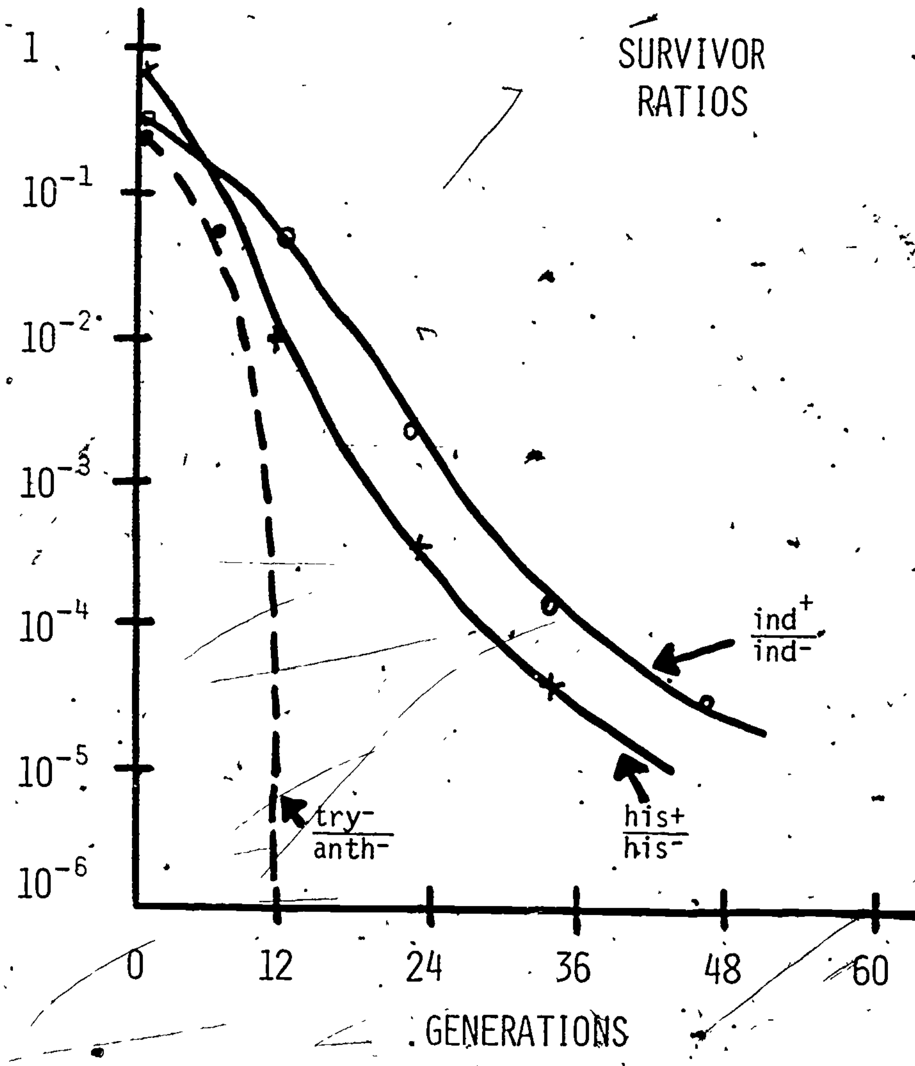


Figure 1. Survival ratio comparisons between normal and back-mutants of the bacteria Bacillus subtilis. See text for details. (Based on S. Zamenhof and H. H. Eichhorn, "Study of Microbial Evolution through Loss of Biosynthetic Functions: Establishment of 'Defective' Mutants," Nature 216:456-8 November 4, 1967.)

TABLE 1

SOME KEY CONCEPTS ON LEARNING MECHANISMS

1. Behaviorally verified learning results in the synthesis of protein.(17)

2. Learning involves small situation-specific clusters of cells strategically dispersed throughout the brain.(18, 25, 34)

3. Protein synthesis requires about one second on the average, whereas thinking occurs within milliseconds.(19) "Learning" is a much slower process than is "thinking."

4. Electrical stimulation of certain areas of the exposed human brain results in involuntary, jerky movement or sounds which evidently bypass the cerebellum.(20) Also, the recall of "lost" memories, the sensation of a familiar smell, etc., can be evoked electrically.

5. The average brain cell has thousands of interconnections with other cells.(21)

6. The vast majority of interconnections are inhibitory.(22, 23)

7. The neonate's brain has relatively few interconnections between cells, evidence of human plasticity. Interconnections quickly accrue, however.(24)

8. Despite exhaustive searching, no specific memory storage locations have been found.(25)

9. Destruction of parts of the hippocampus interferes with long-term memory (either deposition or recall or the incentive to remember).(26)

10. Earthly life forms thus far investigated contain a great many structural and functionally similar microscopic entities. The similarities of terrestial forms of life are much more striking than are the differences.(27)

11. For any relatively autonomous system whatever, the "sphere" (point, circle, sphere, hypersphere) appears to be the preferred "shape," a configuration of minimum "surface," minimum energy and probably maximum efficiency.(28)

12. Wiener has shown that "information" is mathematically equivalent to the <u>negative</u> of entropy.(15)

13. "Information" is measured according to the amount of uncertainty that is removed.(29) In general, for any given message, the amount of information contained (or the amount of uncertainty

removed) varies from one individual to the next.(30) Except for trivial cases, it is currently impossible to measure the exact information content contained in any message. In learning situations it always depends on the learner.

14. "Channel capacity" is defined as the maximum rate at which the exact input message ("source information") can be received without error.(31) A typical learning situation can be considered as a "communication channel" consisting of the source information, the transmission medium and the learner and thus must obey the same physical laws which govern all communication channels. (See text for discussion.)

15. Exceeding the capacity of a communication channel always results in "distortion" (or "mislearning," in learning channels) because part of the source information is not received.(32) What will be omitted can very seldom be predicted. (See text.)

16. In all educational endeavors, self-pacing should be the rule, not the exception; otherwise the pace must be slow enough to accomodate slow learners. It is impossible for any learner to exceed his own channel capacity.

17. Within the first ten milliseconds or so, incoming information that is "unwanted" or "uninteresting" is automatically attenuated. (33, 34) The brain physically intercedes before we have time to "think" about it.

18. Forty or fifty repetitions of unwanted or uninteresting information results in learning anyway (at least, it does in the absence of active rejection by the learner). (34)

19. Learning involves "action" on the part of the learner, at least, in the sense of synthesizing protein and avoiding the rejection or attenuation of the proffered information. Thus for efficient learning, learner motivation is of compelling importance. In general, the learning task must be perceived as personally worthwhile if efficient learning is to occur.

20. The Heisenberg Uncertainty Principle denies the possibility of the "exact" measurement of anything.(35) Measurement changes the object being measured, at least to some small extent. Thus there is a space-time minimum relative size that can be measured. (In other words, the smaller the entity to be measured, the greater the uncertainty.)

21. An incredibly small amount of energy (one photon!) can affect the "output" of a receptive mind.(36) The fact that an almost immeasurably small amount of input energy can affect the outcome of mental processes has profound implications for all learning endeavors and mental measurements.(53) (See text for discussion.)

22. Evidence suggests that humans begin with, and operate from, a "model of the world."(37, 38, 39) If this is so, then any information that is internalized will modify or reinforce the model. Thus we tend to accept or reject information according as it can or cannot be assimilated into the model. Furthermore, gaps in one's knowledge and other discrepancies cannot be discerned by introspection alone. It is necessary to have outside help.

23. Visual input information processing capacity far exceeds all other types of sensory input capacities for humans.(40) (See Figure 2.) The percentages will vary somewhat depending on the method used to estimate the number of cells involved with different types of input information; however, there is reasonably good agreement with respect to the order and relative importance.

24. Man's maximum information output capacity as a channel is surprisingly limited, averaging somewhere in the neighborhood of 15 bits per second.(41, 42) (See Figure 3.)

25. There is evidence that man can handle simultaneously about seven or so "chunks" of information.(42) If an average chunk of information is worth about 15 bits per second, this would imply that man's information handling capacity would total around 105 (±30) bits per second.

26. McLuhan may be right in suggesting that the medium is the message. (43) At the very least, it is an integral part of the communication channel. (See text.)

27. Matching the message and the medium to man's sensory input characteristics allows us to take advantage of man's natural information processing abilities, a much more efficient process. The average English language message (conversations) contains between one and two information bits per character.(44)

28. At present, we can personally produce only a very limited amount of information (say, 15 bits per second on the average). (45) Thus personally constructing an efficient learning experience is, in general, an exceedingly tedious process.

29. The most efficient way to transmit redundant information is not to send any message at all.(46)

30. Dynamic information dominates attention - a scream, a clap of thunder, anything moving within the field of vision, for instance. (47) As the magician will tell you, the eyes look where they are commanded. According to John Ross and his associates, human binocular vision involves a minimum of about 2000 point-pairs per second.(48) Dynamic, binocularly-received visual stimuli thus automatically carry a very high information content that is readily decodable by the brain - a most efficient process.

FIGURE 2

A COMPARISON OF MEASURED HUMAN INFORMATION INPUT CAPACITIES

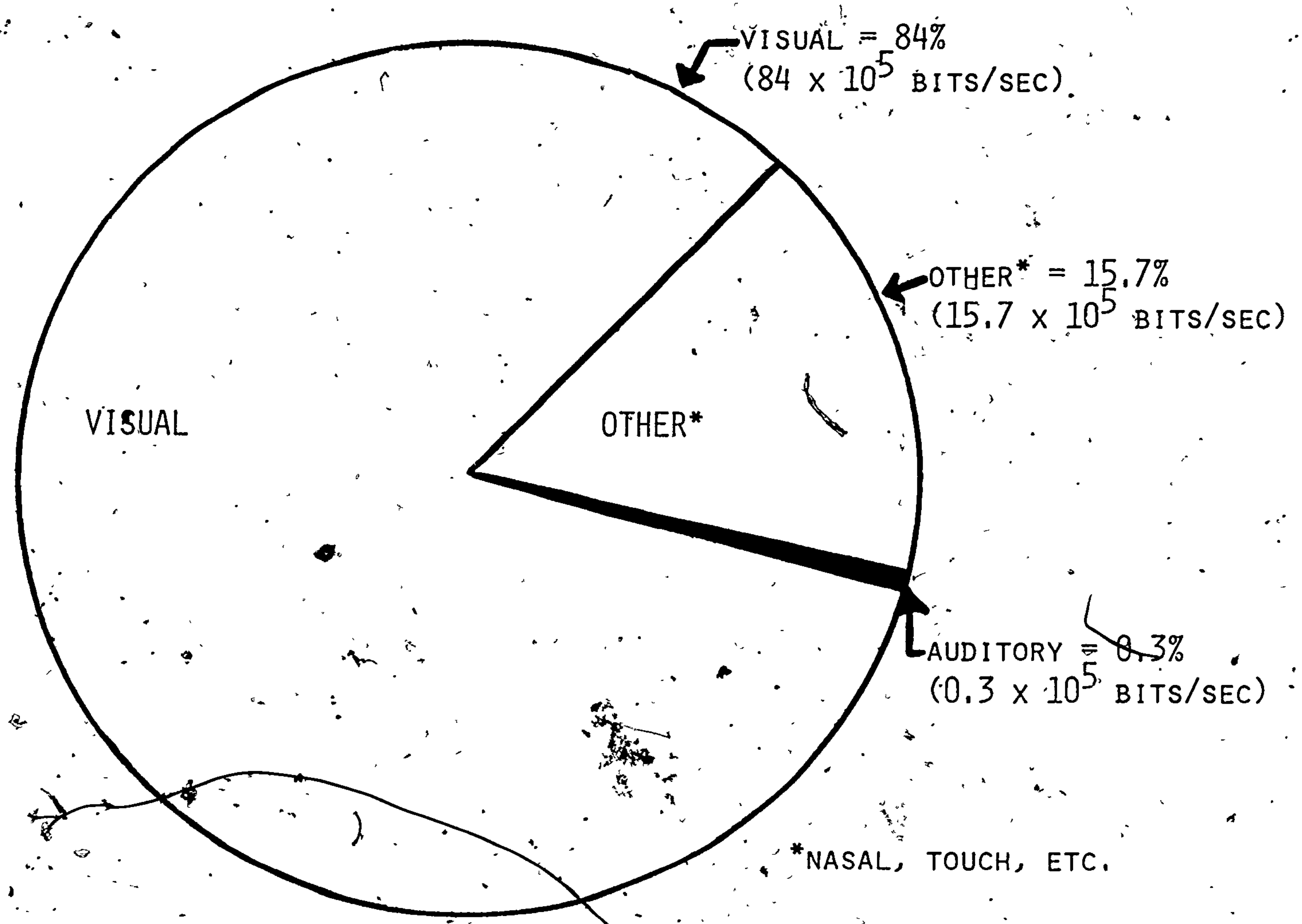
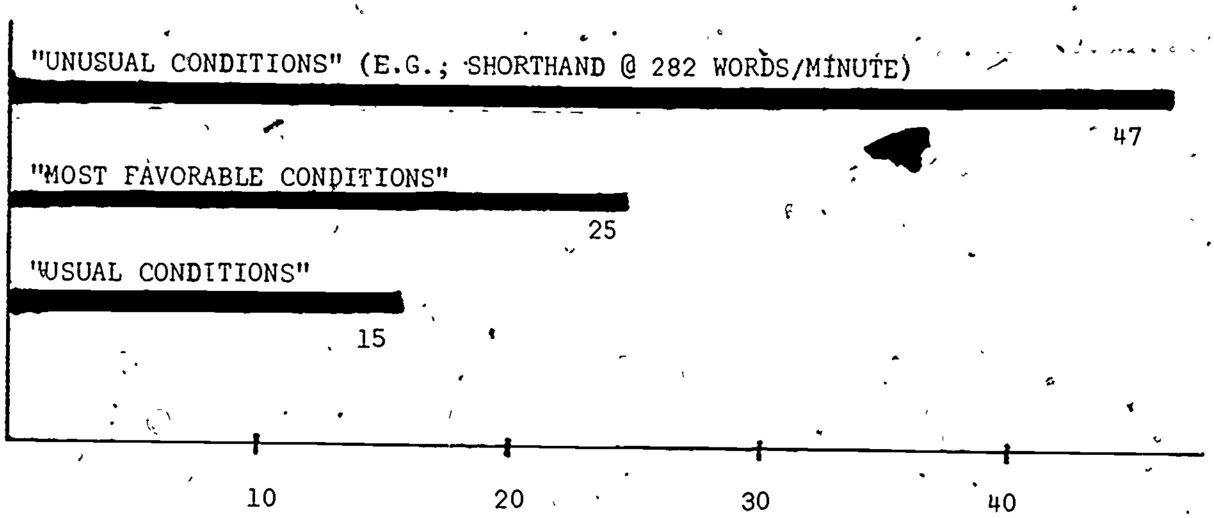


FIGURE 3

SOME MEASURED VERBAL INFORMATION OUTPUT CAPACITIES



Hydén and Lange have conducted a number of enlightening studies concerning the relationship between learning and protein synthesis (concept #1 of Table 1). In one experiment, for example, "right-handed" rats were trained to use their left front forepaw to feed themselves. At the end of twelve 25-minute training periods, the rats were sacrificed and electrophoretic analysis of the hippocampus revealed the typical curves shown in Figure 4. The cross-hatched area labelled "S100" indicates the new structural component. Both trainees and controls have virtually identical curves except that the "S100" node appeared in all trainees and in none of the controls. Furthermore, S100 protein is a common constituent of the brain. From a statistical standpoint, the probability of this difference occuring by chance alone is very small (less than one in a thousand).

This deposition process may explain Linseman and Olds' findings that repetition results in learning of even "unwanted" information.(34) As long as the incoming signals are not actively rejected by the learner, protein synthesis continues and the message eventually becomes a part of the learner.

These findings are particularly interesting because of a famous surgical operation.(26) Parts of the diseased temple lobes of a patient who was suffering from severe epileptic seizures were removed. In removing the tumor, the surgeon also damaged the hippocampus. After the operation the patient seemed perfectly normal. To the casual observer he appeared intelligent and well-behaved. It soon became apparent, however, that he could no longer learn. While he did well on tests of short-term memory, his long-term memory was completely blocked. He could still recall things that had occurred up to the time of his operation (1953) but virtually nothing thereafter. For example, his family moved out of the neighborhood shortly after the operation and he was unable to learn how to reach his new abode. In fact, when tested, he led investigators to his old home.

Hydén and Lange have also shown that the same types of learning cause protein to be synthesized in other appropriate brain areas. Furthermore, a number of informative studies by Barondes, Agranoff, and others have shown that long-term learning does not occur when cerebral protein synthesis (or RNA synthesis) is blocked.(49) Citing these studies, Eccles concludes that "in the process of learning, neuronal activation leads first to specific RNA synthesis and this in turn to protein synthesis and so finally to synaptic growth and the coding of the memory."(50)

It should be remembered, however, that mature neurons neither replicate nor replace themselves. The major (principally excitatory) neuronal network of the brain appears to be genetically determined in great detail and is completed quite early in life.(50) However, the neonate's brain contains relatively few interconnections between cells. (See Figure 5.) The left side of Figure 5 shows a tracing of the brain of a three-month-old child. Twenty-one months later, a similar tracing was made of the same area. Note that the interconnections between cells have increased dramatically.

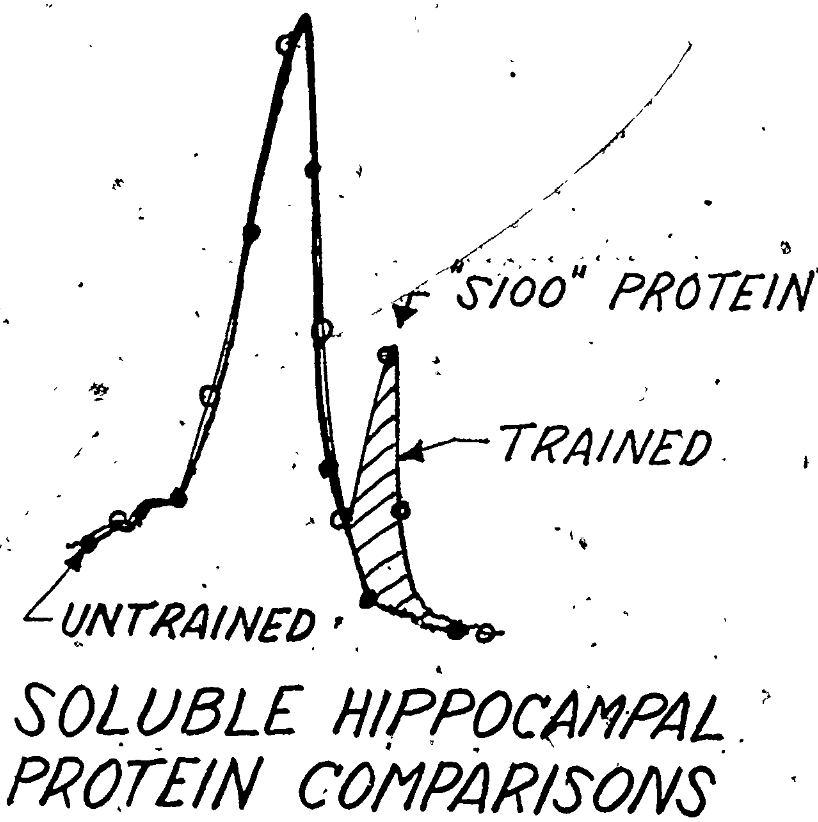
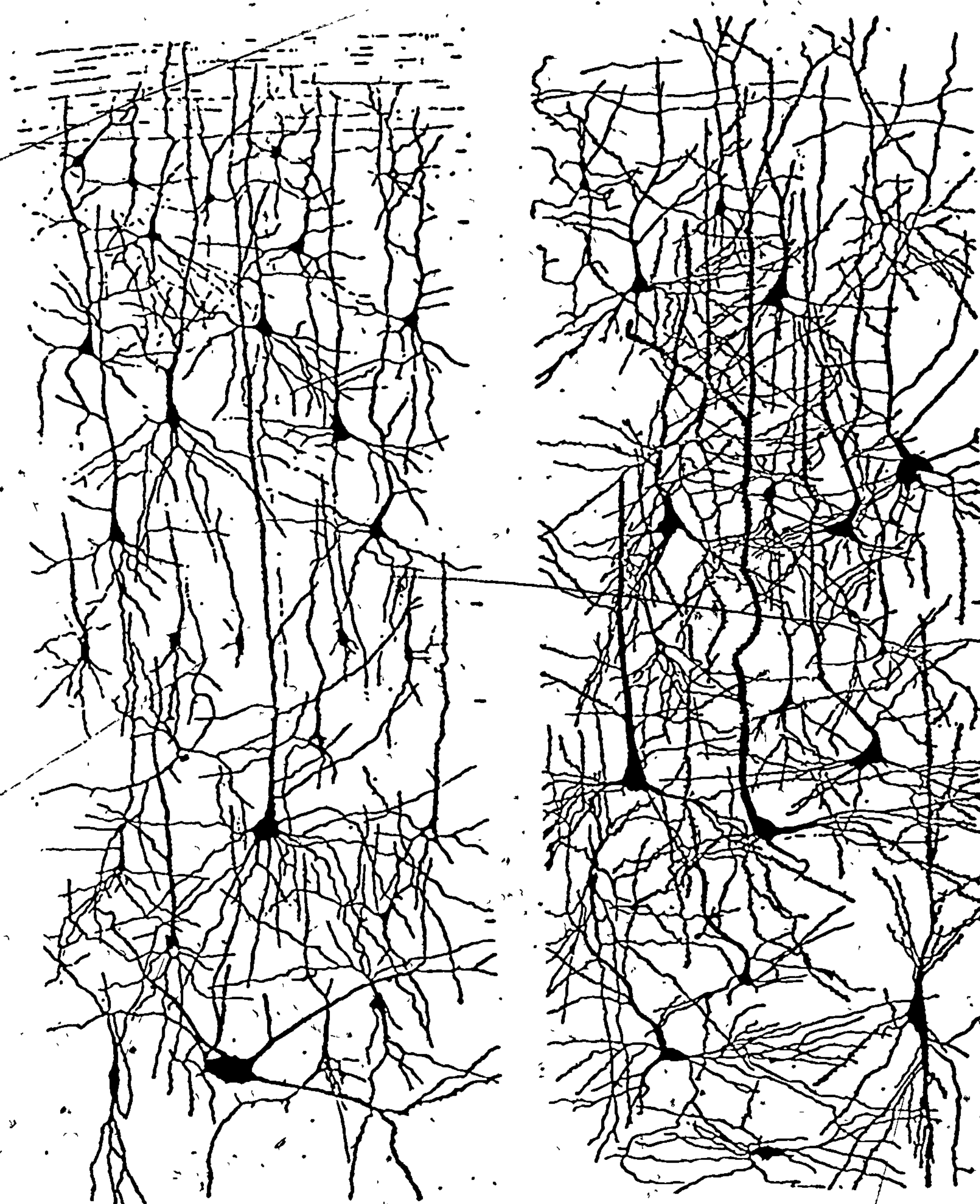


Figure 4. Electrophoretic analysis reveals the typical difference in hippocampal proteins between trained and untrained rats. See text. (Based on Hydén and Lange, "S100 Brain Protein: Correlation with Behavior," Proc Natl Acad Sci 67(4):1959-66.)

HUMAN BRAIN CELL DEVELOPMENT



AGE: 3 MONTHS AGE: 24 MONTHS

Figure 5. Tracings from the same region at the right of the brain of a human infant indicate how the visible connections between neurons develop. (From N. Calder, "The Mind of Man," Viking Press (1970), p. 223.)

Furthermore, most of the interconnections between brain cells are inhibitory.(21, 50) That is, these interconnections for the most part tend to prevent cells from firing, rather than vice versa. Finally, it should be noted that the average brain cell has thousands of interconnections with other cells.

Another important finding is that no specific "memory locations" have been found despite a great deal of investigation. Karl Lashley conducted a most exhaustive study in this regard. He trained rats to proceed through a maze for food and then destroyed one area of the brain after another. Anything that left the animal alive left memory intact.(25)

Eccles notes that "these inhibitory pathways are now known [to] participate very effectively in neuronal integration, molding and modifying the patterns of neuronal responses," and further suggests that inhibition "chisels away at the diffuse and rather amorphous mass of excitatory action and gives a more specific form to the neuronal performance at every stage of synaptic relay."(51) It would come as no surprise, then, for an interstellar visitor to observe that as humans become older they become less flexible, instead of more so, more inhibited, instead of less so, and more prejudiced. For the young, black is very black and white is very white. There are too few cross-connections to enable the young to avail themselves of the shades of gray involved. Young people are "physically" precluded from doing this.

Since these interconnections become a permanent part of us and shape the way we think, the most important challenge parents and educators face is that of providing a proper mix of instructional experiences that will enable learners to avoid acquiring a dysfunctional pattern of interconnections in the first place. It is especially important to avoid a pattern that inhibits further learning.

It is difficult for many of us to accept the notion that as youngsters we almost always acquire a functionally deficient, "inaccurate" structural pattern of hereditarily-prescribed connections and environmentally-induced interconnections. It is impossible to discern basic model-of-the-world deficiencies from within and when this psychologically important, unavoidable ignorance is coupled with feelings of self-satisfaction, correction becomes impossible. This, of course, is a most difficult part of the problem.

However, in light of recent research findings, all is not lost: Under appropriate conditions an incredibly innocuous information input can trigger the human brain.(36) (See Table 1, #21.) But even with remarkable insight and strong motivation, changing one's "way of thinking" is fraught with difficulties for it involves a "corrective" disconnection and re-patterning of interconnections (while at the same time maintaining a workable inner model) all subject to unknown hereditary constraints and temporal considerations.*

*The major neuronal network and the bulk of the interconnections become firmly established early in life. It is no accident that an adult's measured mental functioning seldom changes appreciably.

Earlier we discussed energy-efficiency and mentioned that "information" and "entropy" have been found to be opposite in a mathematically exact manner.(15) Entropy has been recognized since the time of Boltzmann's statistical physics studies in the 1890's as related to the number of alternatives which remain possible for a physical system after all the macroscopically observable information concerning it has been recorded.(52) It thus follows that information is measured according to the amount of uncertainty that is removed. For example, suppose we flip an honest coin. Once the outcome (heads or tails) becomes known, then the "uncertainty" has been removed. This is defined as one "information bit" ($\log_2 2 = 1$). If there are four equal possibilities ($\log_2 4 = 2$) then the outcome represents two bits. One out of eight equal possibilities implies three bits ($\log_2 8 = 3$). And so on....

One way of arranging the letters of the English alphabet is to use a binary coding such as the one shown in Figure 6. Here the average letter is worth 4.7 bits. In this scheme, for example, if the letter J occurs, five bits of uncertainty have been removed. Letter H would be worth 4 bits and so forth. Similarly with the weather map shown. A tiny part of one scan of one line of the T.V. screen would be worth 15 bits for the first code illustrated, 12 for the second method of coding. For any picture, the information content can be estimated by summing all the parts of the scanning process.

Since man's information input capacities have been measured,(40) information channel capacities can be quite analogously represented by the different size funnels depicted in Figure 7. If the scale were accurate, the "visual" funnel would really be about 390 times larger than the "hearing" funnel and about six times as large as the "other" funnel (the remaining senses). From a somewhat different aspect, similar measurements make it clear that our brains can automatically process a great deal of visual information.(48) Shannon and Weaver begin their celebrated treatise "The Mathematical Theory of Communication" with the following passage:

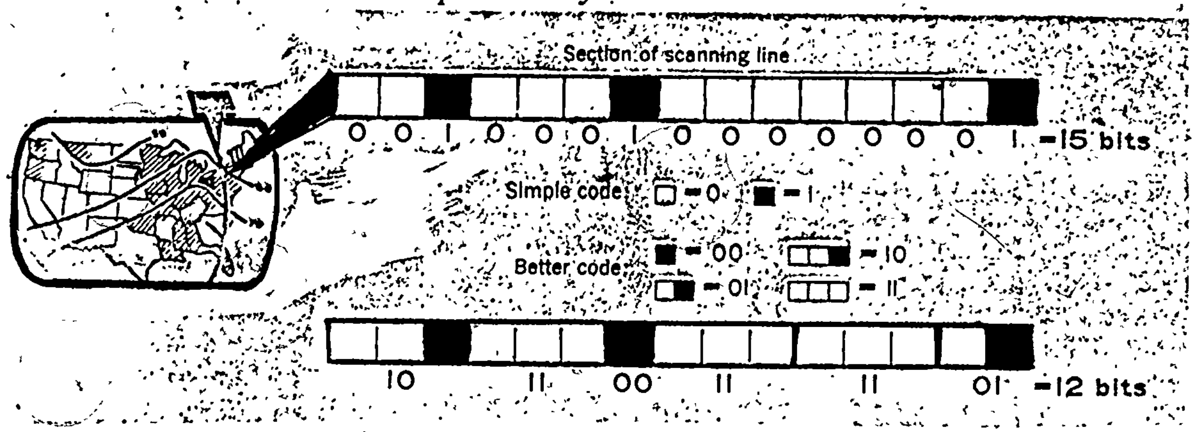
> The word communication will be used here in a very broad sense to include all of the procedures by which one mind may affect another.(52) (Author emphasis.)

A typical learning situation can thus be considered as a communication channel (or, we might say, a "learning channel") consisting of the information source, the transmission medium, and the learner (see Figure 8). Any such channel must obey exactly the same physical laws that govern all other communication channels. This is a point not generally recognized by educators - or at least, it is not well heeded. McLuhan is correct to emphasize that the medium is most important.(43) Unfortunately, however, as Figure 9 suggests, most teaching is aimed at only 0.3% of man's sensory information input capacity.

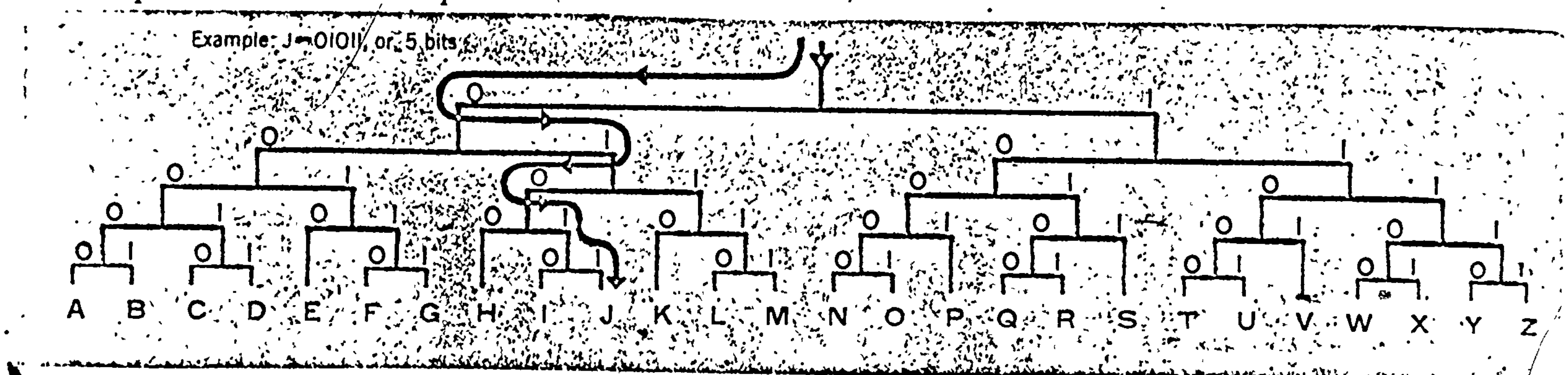
The notion of "channel capacity" is of exceeding importance to all educators even though this is not generally recognized by the educational community. Channel capacity is defined as the maximum rate at which the exact input message (or "source information") can be received without error.(31) Furthermore, exceeding the capacity of a channel always results in "distortion" (or, in a learning channel, "mislearning") because part of the intended information cannot be received.(32) (See Figure 10.) What will be omitted can very seldom be predicted.

FIGURE 6

The weather map, bit by bit

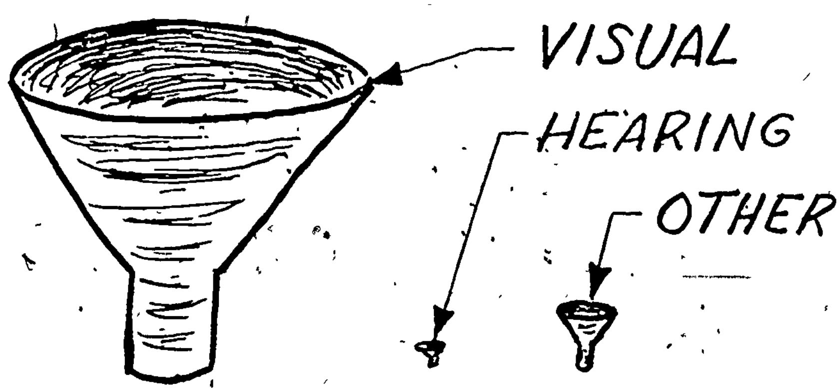


The alphabet in 4.7 bits per letter



(Based on F. Bello, "Information Theory." See reference #42.)

FIGURE 7



COMPARISON OF HUMAN INFORMATION INPUT CAPACITIES

FIGURE 8

LEARNING CHANNEL

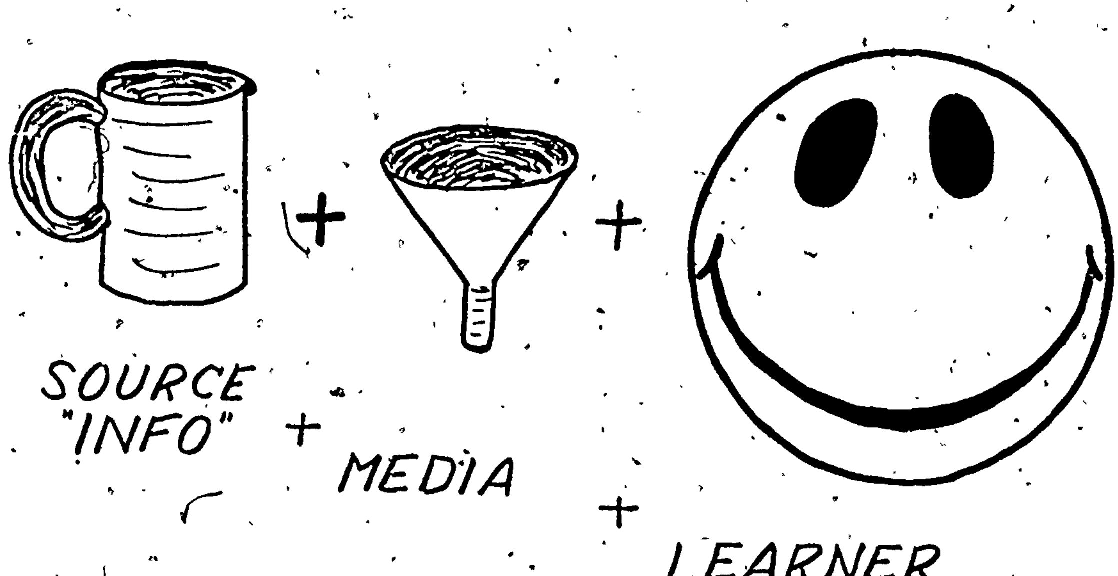
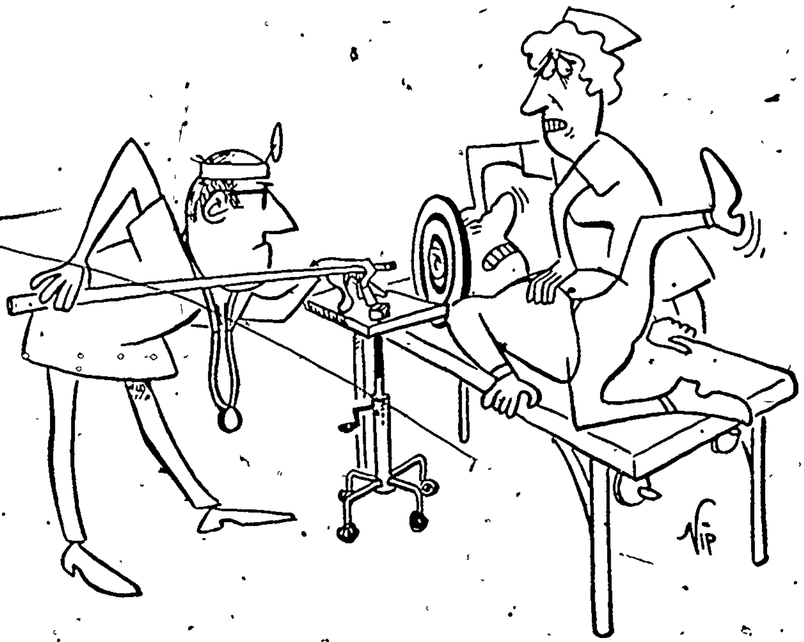


FIGURE 9



Courtesy of International Pharmaceutical Company.

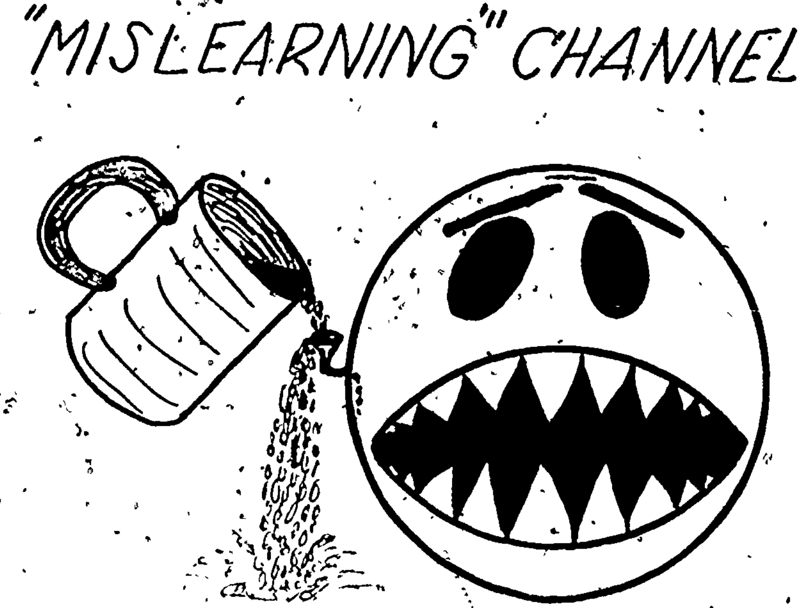


FIGURE 10

In addition, if the learner has shut off his receiver (if he is thinking about something else, for instance, or has gone to sleep, or whatever) the information will not get through. (See Figure 11.) As a consequence of the completely unpredictable nature of the variability of an individual's channel capacity, learner self-pacing should be the rule for all educational endeavors; otherwise the pace must be slow enough and repetitive enough to accomodate the slower learners. No learner can exceed his own channel capacity. Unfortunately, a pace that is too slow interferes with learner motivation and learning efficiency.

Exceeding the channel capacities of learners is a more insidious problem than one might think because of the convincing evidence that every individual begins with and operates from his own model of the world, not directly from the "real" world *per se*.(37, 38, 39) For example, in Figure 12 (the Müller-Lyer illusion) the vertical bars are the same length, but most people quickly reject this possibility because it contradicts their personal model of the world.

Each of us tends to accept or reject information according to whether it can, or cannot, be assimilated into the model. Further, attenuation (or rejection) of unwanted, uninteresting information occurs by automatic "physical" intervention before we have time to "think about it."(33, 34) (See Table 1, #17.) For these and other reasons, gaps in one's knowledge cannot be discerned by introspection alone.

Three things seem particularly important to keep in mind:

1. Because each model reflects a relatively permanent, inter-connective brain cell pattern that enables us to promptly reject incompatible information automatically, as suggested earlier, it is of primary importance that we help learners to *avoid acquiring a dysfunctional model in the first place*.

2. Distortions caused by exceeding the learner's (or the medium's) channel capacity are almost impossible for learners to detect since incomplete, incompatible information is automatically rejected or made to fit one's own model of the world.

3. Because each model becomes an integral "physical" part of the individual, no one can detect his own shortcomings in this regard. He must have outside help and even then it may be impossible (or nearly so) to effect meaningful alterations. For this reason, Einstein was completely unable to convince most of his contemporaries of the veracity of the theory of general relativity.(65) Except for the very few who had acquired an open, questionning model of the world, his ideas had arrived too late, did not fit their established preconceptions and, of physical necessity, simply had to be rejected. This is a common experience.

Finally, there are two related findings of fundamental importance. One concerns the Heisenberg Uncertainty Principle.(35) For a long time it was accepted

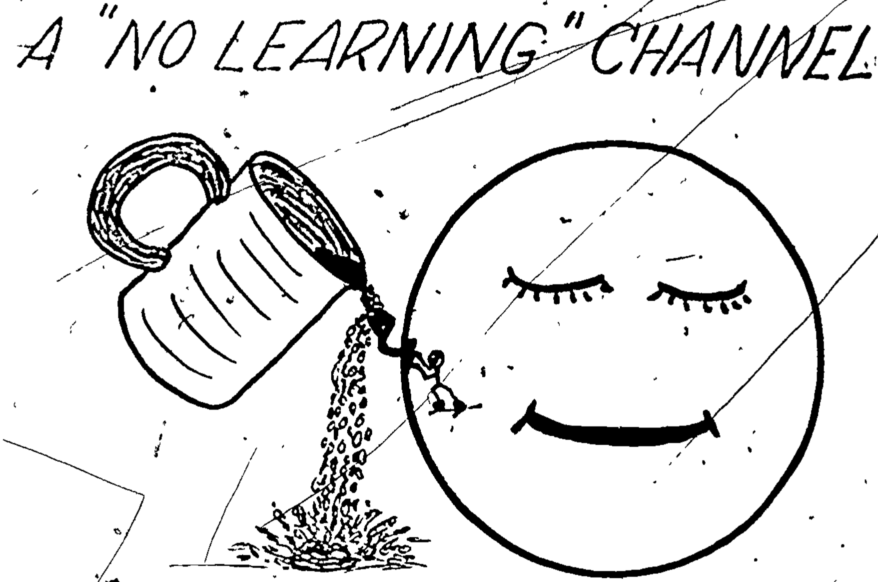


FIGURE 11

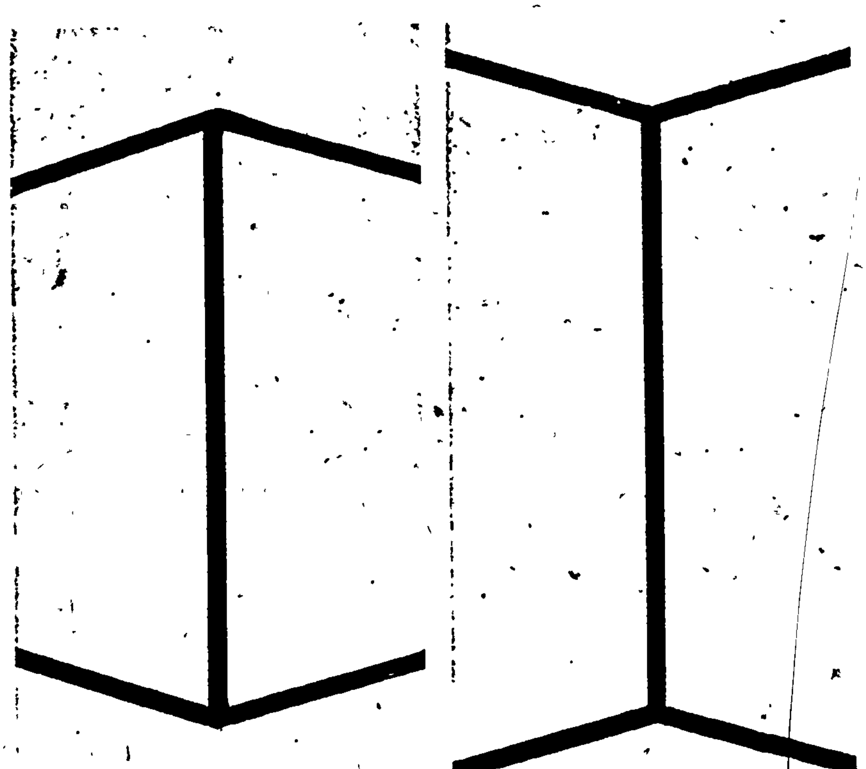


FIGURE 12: The Müller-Lyer illusion

that, in principle at least, we could always refine our measurement process to determine within arbitrarily close limits the "true" dimensions of any physical entity being measured. However, Heisenberg proved that even in principle this is not the case. There is a very definite limit to the smallest entity that can be measured. This means that we cannot determine both the velocity and the location of an "electron" with certainty nor will we ever be able to determine anything of an exact nature about that entity.

This takes on new meaning because of the research findings of Sakitt.(36) She has been able to furnish convincing evidence that an incredibly small amount of energy can affect the output of a receptive mind. As a result of this and the Heisenberg Uncertainty Principle, it seems obvious that (in contradistinction to the abundance of learning cause-and-effect data) the "cause" of any learning outcome is impossible to determine with certainty and thus behavioral research outcomes of mental functions, no matter how carefully executed, will always be subject to widely varying interpretation. As with the case of the link between cigarette smoking and lung cancer, only an overwhelming preponderance of statistical "evidence" is likely to prove convincing.

By the way, it is worth noting that no individual can, by his own personal efforts, expect to have much lasting effect on anything or anybody. The reason that this is so stems from the fact that man's maximum personal information output is so limited.(41) This is also why our actions, our facial expressions our gestures speak louder than our words - these usually carry far more information. About the best we can do is to search for learner's triggering mechanisms, those key queries which help learners to discover important deficiencies in their own model of the world and thereby to develop the motivation and the determination necessary for the arduous task of modifying established habits of mental functioning.

Even when one is aware of personal limitations, it's still not easy to accomplish much. The typical lecture is illustrative: Seldom does even the most enlightened instructor have the time and other resources necessary for wise selection of source information and media. Movies and television, on the other hand, usually provide the combined information output of hundreds (sometimes thousands) of individuals and thus can furnish good examples of some effective solutions. An hour of videodisc, for example, can remove as many as 10^{11} bits of uncertainty in providing an hour of television viewing.*

From the above considerations and the key concepts listed in Table 1, it is possible to specify a succinct list of what is necessary for the optimal "packaging" of information for efficient utilization by learners. (See Table 2.)

Construction Concepts

From these guidelines, our reasoning progresses along the following path.

*For most of us they don't, however. Most such presentations are highly redundant and thus carry very little information. If the source information was imaginatively selected for viewer needs, instead of sponsor needs, we'd all be better off.

TABLE 2

REQUIREMENTS FOR OPTIMAL INFORMATION PACKAGING
1. MATCHING THE SOURCE INFORMATION AND THE TRANSMISSION MEDIUM TO THE LEARNER'S INFORMATION PROCESSING CHARACTERISTICS AND OTHER PERSONAL NEEDS.
2. A SELF-PACING, INTERACTIVE FORMAT.
3. ADEQUATE LEARNER MOTIVATION.

If one stops to think about it, everyday life provides the mix of sensory information that best matches human sensory input characteristics. Unfortunately the message content is often of a misleading, random nature with key elements scattered over time and between other events. However, if one were to "collect" all the necessary "scenes," place them in logical order, require decisions to be made by the learner at the appropriate places and times, and provide prompt, specific, unambiguous feedback, it would be a very powerful learning tool indeed. In other words, were we to pick a suitable learning situation, simulate it as realistically as possible (except with respect to the actual time required and unnecessary distractions) and provide appropriate feedback, we would have developed a means of packaging the information for very efficient learning.

For example, it is very difficult to learn much from managing patients with long-term, chronic disease: Patients move about; they change doctors or discontinue seeing any physician at all; they fail to heed medical advice or to follow instructions with sufficient care; they see doctors only when they consider it to be really necessary (perhaps after it has become terminal); etc. Furthermore, a physician may well forget what exactly it was that was recommended or prescribed in years past for a particular patient, and even with perfect recall, it may still not be possible to determine whether or not the patient actually followed the instructions. Under such circumstances, it is most difficult for any physician to determine the true merit of a particular therapeutic strategy.

However, it is possible to construct a simulation in accord with the foregoing concepts so that a lifetime of dealing with a chronic patient can be compressed into a half hour or so. At each successive stage of managing such a simulated patient, the physician is provided with information concerning the effects of previous interventions (as well as other intermediating circumstances and conditions) so that a basis for subsequent management decisions is developed. The simulation eventually reaches a conclusion based on the physician's own pattern of decisions. This interactive, "decision-action-results" structure typically stimulates a high degree of personal involvement, brings important issues into sharper focus and fosters a receptive mental climate. A summary analysis can then be more readily assimilated, more fully understood, and more completely internalized for subsequent utilization with real patients.

This is the essence of the approach followed in developing simulated patient encounters for physicians' self-assessment and for the training of residents and medical students. In one simulation, for instance, if the physician elects to perform a rectal examination, he is referred to a model which represents the appropriate pathology realistically. For another the physician must examine the "fundus" of a model.

The format guarantees learner interaction and allows self-pacing automatically. For the patients simulated by the PLATO* computer, for instance, nothing happens until the learner "touches" the screen of the terminal indicating the action (or actions) decided upon. Use of the computer allows for great flexibility. In one simulation, for example, the physician must take proper action within about 120 seconds (real time) or the patient dies. Other

*PLATO - Programmed Logic - Automatic Teaching Operation(54) subtleties are included. The methods we utilized have been completely described in a recent publication by the American Medical Association.(55)

As shown in Table 3, these simulations were tested at a number of national and regional medical meetings. Of an estimated 3000 physicians and health professionals, 846 were asked for their reactions. Better than ninety percent of the participants found the simulations interesting, instructive, challenging, useful and thought that they "rang true." Table 4 indicates the results.

ON THE CHANGING OF THE GUARD

If we consider whether schools in general provide learning experiences which satisfy the requirements shown in Table 2, it seems obvious that most do not. Insofar as the type of learning with which schools are ostensibly concerned (the "three r's," etc.), the average school year could probably be replaced by a few short, intensive, efficient workshops. However, because learning is a continuous process, a lot of unintentioned, unstructured learning is always going on in the classroom. As McLuhan's analysis so accurately suggests, the principal information input has to do with the classroom itself and with the institution of education *per se*.(56) Students learn how to "do" education.*

Instead of employing authority figures to "tell it like it is," it seems to me that we need to hire capable, enthusiastic learners who can help students learn how to direct and focus and evaluate their own learning and to raise questions about why "it is like it is." But the Old Guard authority figure is such a univeral, culturally-ingrained part of our existence, it seems almost impossible to change.(57) Parents and teachers tend to feel uncomfortable when too many questions are raised - especially questions that lead to more questions. Furthermore, Postman and Weingartner argue that even those teachers with insight and incentive are unable to be effective because of the highly constrictive educational climate which results from enforcing course requirements "rather than helping the learner to learn."(58)

However, schools do serve very necessary societal needs. They excel at repetition and so are ideal for instilling cultural values and customs that might otherwise be rejected. This is an important function, of course. Learner motivation for subject matter instruction is probably impossible to secure anyway, at least under typical circumstances. Furthermore, it's no doubt preferable to have youngsters safely in school rather than underfoot at home or out in the streets getting into trouble. And it's usually cheaper than hiring a babysitter.

For institutions that provide professional training, the situation is only somewhat different. As mentioned earlier, professional schools are in many ways very much like the schools that educate our kindergarten and early elementary students. Like kindergarteners, professional students are for the

*Postman and Weingartner note that McLuhan invites us "to see that the most important impressions made on a human nervous system come from the character and structure of the environment within which the nervous system functions."(66)

TABLE 3

Demonstrations of Test Simulations

1. Second AMA Physician Self-Assessment Workshop, Chicago (May 31 and June 1, 1973).
2. AMA Annual Convention, New York (June 23 - 27, 1973).
3. Association of American Medical Colleges, Washington, D.C. (November 4, 1973).
4. American Board of Medical Specialties' First Invitational Conference on Recertification, Houston (March 1 - 2, 1974).
5. AMA Annual Convention, Chicago (June 22 - 27, 1974).
6. Fourth National Conference on Continuing Medical Education for State Medical Associations and Specialty Societies, Chicago (October, 1974).
7. American Academy of Dermatology Annual Meeting, Chicago (December 8 - 12, 1974).
8. American Academy of Family Physicians National Meeting, Chicago (October 6 - 9, 1975).
9. North-Central Region Family Physicians "Refresher Course," Iowa City (February 19 - 23, 1976).

TABLE 4

TEST RESULTS

An estimated three thousand individuals have participated in the SIMPLE* simulation demonstrations. Of these, 846 were requested to respond to the below questions. The very high percentages of "yes" responses confirms that SIMPLE simulations are very acceptable to physicians and other health professionals.

Question: Did you find these

Responses:

1.	Interesing?	Yes = 99%
2.	Instructive?	Yes = 94%
3.	Challenging?	Yes = 91%
4.	Useful?	Yes = 97%
5.	Rang true?	Yes = 90%

*SIMulated Patient Learning Encounter.

most part highly motivated, at least with respect to satisfactory completion of obligatory training and institutional requirements. But professional schools suffer many of the same telling* deficiencies as other schools.

Rare is the professional school that allows students to experience a significant number of self-pacing, interactive educational experiences. The lock-step, lowest-common-denominator, redundancy-paced curriculum is typical. Instead of matching the educational message and medium to individual learner characteristics, most institutions try to match learners to instructional characteristics. We do this by selecting homogeneous groups of entering students who match as closely as possible students who have successfully struggled through in the past.

If we were to lose this selection privilege today, there would be pandemonium in the Ivory Towers before tomorrow. Very few institutions could cope with the problems of tailoring instruction to fit the characteristics (and needs) of individual students with different backgrounds. The predictable response would probably be a clucking of tongues, a rolling of eyes, a shaking of heads, and a "quantum leap" in the failure rate. However, the era of complete freedom with respect to selection privileges seems to be on the wane. As more minority and disadvantaged groups become successful at opening the doors of our hallowed institutions, the problems will become more intense, perhaps more obvious.

Some schools located in urban centers are already under pressure. Publicly-supported medical schools in Holland are no longer permitted a free choice of students.(59) Instead, students must pass certain minimum requirements to gain access to the pool of eligible candidates. Openings are then filled by national lottery. On average, only one student in twelve attends the same school as she or he would have under the old free choice system. It will be interesting to observe the results of this innovation over the next decade or so.

So What Should We Do?

Considering mankind's general trend toward greater efficiency, it is of interest to note that skillfully executed apprenticeship, one of the most venerable of our educational tools, is still our most efficient method for promoting learning. It employs every sense modality to the fullest.

Unfortunately, as we shall see, it is just as efficient for teaching the wrong things as the right. Bad habits and misconceptions acquired in apprenticeship training are exceedingly difficult for the learner to eradicate even if he wants to. The best hope lies in furnishing retraining by using better methodology. However, even then, unless there is sufficient incentive for the learner to acquire and utilize the new modus operandi, nothing will prove effective. For example, most physicians have given up smoking (especially in clinical settings and in other public areas where self-contraditions could be embarrassing). They are obliged to advise patients to quit smoking,

*Hmmm...

recognize that the doctor who obviously fails to follow his own advice soon loses credibility and are consequently rewarded for giving up the habit. Nurses, on the other hand, are under no such compulsion and have not given up smoking.(60)

Many otherwise excellent retraining programs for correction of addiction to drugs, crime, food and/or drink are doomed to failure because under the conditions of today's society it is virtually impossible to supplant such habits with more acceptable behaviors that are sufficiently rewarding to the "students."

After apprenticeship, simulations and games come next in educational efficiency, especially if they realistically mirror important situations.

The essential differences between games and simulations are not always distinct. Games that are educationally effective usually simulate one or more aspects of life situations quite realistically. On the other hand, simulations, to be effective and realistic, must incorporate some of the typical dilemmas that are an important part of the game of life. "Playing house," for example, is both a game for children and an accurate simulation of parental behaviors. Computers, films, videotapes, videodiscs, anatomical models, actors and actresses, etc., can be used in ways which enable simulations and games to approximate life, and even apprenticeship methods, more closely and often, more instructively.

So what should we do? A number of things come to mind. Of these, three seem particularly important (see Table 5):

1. <u>Provide more "on-the-real-job" experience.</u>

   The training experiences we provide professional students seldom reflect very well the real situations to be faced later on. In training medical students, for instance, we provide clinical experiences which are procedure-oriented, are hospital-based, deal almost exclusively with highly atypical patients that are interesting to researchers and exclude the tedious-to-handle, mundane problems so commonly encountered in daily practice. Compounding this problem of providing training with the unusual (instead of both usual and unusual) is the fact that we generally use apprenticeship-like methods that instill habits of thinking and doing which are exceedingly difficult to erase or modify later on. Worse yet, we tend to glamorize the latest surgical techniques, "wonder drugs" and invasive procedures which interferes with the physician's motivation to learn when and how to avoid inappropriate applications.

   It is sadly ironic that the most effective educational experiences we provide our students teach them the wrong things and make it difficult for them to realize it. Providing more on-the-real-job experiences would help.* Even kindergartens provide field trips.

*In an excellent article on continuing medical education, Stern recommends a swapping of "jobs" by senior residents and practicing physicians. Insofar as we are able to guarantee that the patients receive proper care and that both residents and physicians learn the right things, it's a great idea.(61)

TABLE 5

REQUIREMENTS FOR IMPROVING LEARNING EFFICIENCY:

1. ON-THE-REAL-JOB EXPERIENCES.
2. REALISTIC SIMULATIONS AND GAMES.
3. LEARNER CONTROL OF PACING.

The provision of *"on-the-real-job"* training experiences probably could be universally implemented within a short time if everyone was receptive to the idea. But this is not the case, of course. The relatively permanent, interconnective brain patterns of the majority of professional faculty and administrators would force automatic "physical" rejection of such ideas. To effect a quick change of this magnitude would require a revolutionary process. This is neither practical nor desirable.

The answer to implementation problems like this one lies in finding ways to speed "evolutionary" change. The best tool we have at our disposal is redundancy: like effective advertising, the message should be repeated as often as possible (preferably the same one, but in varying contextual settings) until it gradually becomes an accepted fact of life.

2. Simulations and Games

Next, in addition to *"on-the-real-job"* training, we should provide students with exposure to important, realistic simulations and games. As mentioned above, it is impractical to expect significant changes with respect to providing enough meaningful outside experiences. However, it may be practical to let more reality come in (at least on a "foot-in-the-door" basis). Besides the "swapping" recommended by Stern (62), we should at least be able to provide professional students with educational experiences which simulate important aspects of the real life situations they are likely to encounter after "graduation." Furthermore, we should do away with all notions of "graduation." Educational milestones should be handled like birthdays.* More are always on the way.

Because of the great potential for continuing education, computer simulations are especially attractive. In medicine, for example, once a suitable assortment of simulated patients are on-line and once "artificial" intelligence comes of age, it should become possible to stimulate the patient sitting in the doctor's office so that important information and etiological possibilities are not overlooked. In the meantime, students should be provided with hands-on experiences with computer simulations so that they can gain first-hand knowledge of the difficulties, as well as the exciting possibilities, of an extremely powerful, personally useful tool for the future professional.

3. Learner Control of Pacing

Finally, we should allow students more opportunity for self-pacing. In the final analysis, acquiring knowledge and skills is always a personal undertaking. How long it takes is also personal, varying from one individual to the next. Whenever possible, pacing should be left entirely to the student. It only makes good sense to do so.

*There seems to be a great deal of confusion with respect to personal indeterminancy and aggregate (Markov) processes. For example, it may not be possible to determine how long is ideally necessary for any one student to complete various "milestones" but we should be able to determine with accuracy and reliability how many students in sum are likely to be undergoing what kind of training at most any time. Individual freedom and good planning are not incompatible.

Of "Immovable Objects" and "Irresistible Forces"

Many professional training institutions find themselves saddled with the immovable object of anachronistic policy that is not compatible with the irresistible force of rapidly changing circumstances. A collision sooner or later seems inevitable.

If we consider medical practice, for instance, a recent example may illustrate this growing problem. In an article published in a prestigious medical journal a couple months ago, a distinguished professor of one of our most respected medical schools - one that has one of the lowest student-faculty ratios in the country - suggested that it may not be possible for American medical schools to provide the kind of training experiences that will enable minority students to measure up to "reasonable standards." Citing a case in which a medical degree was awarded "in desperation" (after five years) to a student who had failed to pass the requisite National Board of Medical Examiners' examination five times in a row, he suggested that "considerations of tact and guilt over our history of enormous racial injustice have made it difficult to face the problem of properly balancing our obligation to promote social justice with our primary obligation to protect the public interest."(63)

Curiously, the "Affirmative Action Program" at this same institution is able to recruit minority students from almost anywhere in the country and has been described as "extremely successful."(64)

We presume that "successful" means that they are better able than most to select a target number of minority students who possess reasonably comparable backgrounds to that of former students.

However, it is even more curious, it seems to me, that there has as yet been no clamor for professional training institutions to discard training methods which cannot meet the needs of individual students whose minds have been shaped by very different hereditary and experiential backgrounds. But I assume that it's coming.

In the meantime, it might be well to begin mending our fences so that we will be better able to withstand the strains of change. After all, there should be something besides subject matter and student age which differentiate professional schools from kindergartens.

Or should there?

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5. JAMA Medical Education Supplement (January, 1975) 231:21. See Table 20.

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7. Malpractice rates climbed rapidly. For example, during the last decade the rates for University of Iowa Hospital physicians have increased by 1800 percent. We have been assured that this is typical. For a thoughtful analysis of the effects of patients' new expectations on malpractice awards see David Rubsamen, "Medical Malpractice," Sci Amer (August, 1976) 235(2): 18-23.

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12. The whole history of life on earth can be accurately characterized as a continuous period of increasing efficiency, for equivalent or superior results have consistently been obtained with smaller and smaller expenditures of individual and collective energies. This is not to suggest that the Second Law of Thermodynamics should be repealed; rather, because the space-time framework of earthly life is but an exceedingly small part of the overall cosmic picture, local entropy can be minimized without observable untoward effects for a very long time. The concept of man's inherent drive for greater efficiency is of fundamental importance, but unfortunately it's far too complex a subject to discuss meaningfully at this time. What is needed, it seems to me, is an "Understanding Efficiency" treatise which traces this unifying force from the first "intelligent" cell to quantum mechanics/electrodynamics and general relativity concepts and which then explains the subtle effects of efficiency on our everyday existence.

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18. H. Hydén and Paul Lange, reported in N. Calder, "The Mind of Man," Viking Press, N.Y. (1971) p. 120.

19. The hundreds (or perhaps thousands) of operations called into serial action for ordinary speech, for instance, suggest a timespan of less than a millisecond, while protein synthesis requires about one second on average. Holger Hydén, "Biochemical Aspects of Learning," Proceedings of the American Philosophical Society, Vol. 111, No. 6, Philadelphia, December, 1967, p. 330.

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26. Brenda Milner, "The Memory Defect in Bilateral Hippocampal Lesions," Psychiat Res, Report #11 (1959) pp. 43-51. See also Neal Miller, "Laws of Learning," in Proceedings of the American Philosophical Society (Dec. 11, 1967) Vol. III(6): 315-25. Also see N. Calder, "The Mind of Man," Viking Press (1970), pp. 109-111.

27. Lewis Thomas, "The Lives of a Cell," Bantam Books (1974) pp. 81-87.

28. Mathematically speaking, setting the spherical volume-rate-of-change equal to "zero" yields the formula for a spherical surface area which in turn suggests the minimum volume change occurs for circles, spheres, etc. Also, most cells develop in a spherical shape in the absence of larger exterior forces; usually it's more efficient, time-energywise to minimize the ratio of surface to volume (which means a "spherical" shape).

29. Flipping a coin removes one bit of "uncertainty" as to what outcome occurred (i.e., $\text{Log}_2\ 2 = 1$ "information bit"); similarly, drawing one of four similar golf balls from a hat removes two bits of uncertainty (i.e., $\text{Log}_2\ 4 = 2$ "information bits"): etc.

30. For excellent examples see W. Ross Ashby, "An Introduction to Cybernetics," Chapman and Hall, London (1956) pp. 123-4.

31. Toby Berger, "Rate Distortion Theory," Prentice-Hall (1971) pp. 1-11.

32. Ibid., p. 7.

33. R. Hernandez-Peon, H. Scherrer and M. Jouvet, "Modification of Electrical Activity in Cochlear Nucleus during 'attention' in Unanesthetized Cats," Science, Vol. 234 (1956) pp. 331-2. Signals from the cochlear nucleus of interesting sounds were not attenuated, whereas other relatively loud (but uninteresting) sound signals were quickly subdued before transmission to the receptor cells within the brain.

34. Linseman, M.A. and James Olds, "Activity Changes in the Rat Hypothalamus, Preoptic Area and Striatum Associated with Pavlovian Conditioning," J. of Neurophysiology, 36; Vol. 6 (Nov., 1973) pp. 1038-50. Olds and his associates have been able to demonstrate that a very quick (ten milliseconds) attenuation response occurs and also that forty or fifty repetitions will result in the gradual assimilation of the new information even for stimuli which are at first rejected by the subject.

35. Werner Heisenberg, "Physics and Beyond" (A. Pomerans, tr.) Harper and Row (1971), contains his very readable reflections on the difficulties of overcoming conventional thinking in this regard. Also see N. Wiener (op. cit.) for an excellent discussion regarding "Heisenberg's great contribution," pp. 92-3.

36. Barbara Sakitt, "Canonical Ratings," Perception and Psychophysics, Vol. 16 (1974) No. 3, pp. 478-88. Also, B. Sakitt, "Counting Every Quantum," J. Physiol (1972) 223: 131-50.

37. See Harry Jerison, "Paleoneurology and the Evolution of the Mind," Sci Amer, 234(1): 90-101. For an artificial intelligence research point of view see Marvin Minsky, "A Framework for Representing Knowledge," in P.H. Winston, "The Psychology of Computer Vision," McGraw-Hill (1975), pp. 211-80.

38. Richard Gregory, "Visual Illusions," in Richard Held (ed.), "Image, Object, and Illusion," W.H. Freeman (1974) pp. 48-58. The illustrations in this article are particularly effective in demonstrating how an individual's model-of-the-world modifies the interpretation of real situations. For auditory model conflicts, see Diana Deutsch, "Musical Illusions," Sci Amer (Oct, 1975) 233(4): 92-106 and D. Deutsch, "An Auditory Illusion," Nature (Sept. 27, 1974) 251(5473): 307-9.

39. Hadley Cantril (ed.), "The Morning Notes of Adelbert Ames, Jr.," Rutgers Univ. Press (1960), pp. 7-9. Ames presents a particularly cogent, brief analysis concerning the uniquely personal "world" of each individual. The "world" disclosed by our senses may or may not correlate well with "reality." As he put it in 1943, "The fact that we can never know what we commonly consider as facts and truth is rather appalling. It is as if nature had set about to create a super hoax with humans..." (p. 4) (Author emphasis)

40. H. Jacobson, "The Informational Capacity of the Human Ear," Science, 1950, 112, pp. 143-4 and H. Jacobson, "The Informational Capacity of the Human Eye," Science, 1951, 113, pp. 292-3.

41. Dean Wooldridge, "The Machinery of the Brain," McGraw-Hill (1963), pp. 188-93.

42. Ibid., p. 190. Also see Francis Bello, "Information Theory," Fortune (December, 1953), pp. 136-58.

43. Marshall McLuhan, "Understanding Media," N.Y., New American Library (1964) p. 7.

44. Shannon suggests that because of context and redundancies the average value is probably closer to one bit per character. See Francis Bello, "Information Theory," Fortune (Dec., 1953) pp. 136-58.

45. Wooldridge (op. cit.) p. 190.

46. See C.E. Shannon and W. Weaver, "The Mathematical Theory of Communication," University of Illinois Press, Urbana, (1949), p. 13 and p. 20.

47. Lettvin, Maturana, McCulloch and Pitts, "What the frog's eye tells the frog's brain," Proc Inst Radio Engr (1959) 47: 1940-51. Also see John Z. Young, "A model of the brain," Clarendon Press, Oxford (1964) p. 53, for more of an information theoretic viewpoint.

48. John Ross, "The Resources of Binocular Perception," Sci Amer (March, 1976) 234(3): 80-86. Because the human brain tends to make sense of randomized, computer-generated patterns of points, Ross concludes that humans "adopt a perceptual attitude in order to comprehend the world."

49. S.H. Barondes, "Multiple Stress in the Biology of Memory," in F.O. Schmitt (ed.), The Neurosciences, Rockefeller Univ. Press, New York (1970) pp. 272-8.

50. John Eccles, "The Understanding of the Brain," McGraw-Hill (1973) pp. 183-4. Chapters 3, 4 and 5 are especially pertinent and present a good overview of this complex functioning.

51. Ibid., p. 89.

52. Shannon and Weaver (op.cit.) p. 3.

53. As Ames implies (and Whitehead before him), there is no conflict between "free will" and "determinism." Either concept can be invoked retrospectively to "explain" any event whatsoever. The conceptual difficulty we experience because of evidence that underscores the basic indeterminate nature of life, on the one hand, and the apparently finite number of "Markov Chain" choices, on the other, probably reflects our inaccurate, but very typical, individual internal models of the world that recognize space (objects) and time as distinct entities in an extremely large, but essentially finite, progression of unidirectional events (for example, beliefs in the existence of an "actual" beginning and/or end). See Ames' essay, "Re: Whitehead and Pragmatism" and his correspondence with Dewey in H. Cantril, "Morning Notes of Adelbert Ames," Rutgers Univ. Press (1960), pp. 3-4, 20-21 and 216-27. As always, our model tends to make us reject information that can't be comfortably fit and the communication of any such ideas is thus made more difficult.

54. Alpert and Bitzer, "Advances in Computer-Based Education," Science, (167), pp. 1882-90, 1970. Also see Stanley Smith and Bruce Sherwood, "Educational Uses of the PLATO Computer System," Science, (192) pp. 344-52.

55. John Lackmann, "Simulation and Self-Assessment," American Medical Association, Department of Continuing Education (1976) pp. 15-94 and 101-29.

56. McLuhan (op. cit.) pp. 23-4. McLuhan suggests that "the 'message' of a medium...is the change of scale or pace or pattern that it introduces into human affairs." In other words, the manner in which the medium affects the transmitted information becomes a "part" of the message, perhaps the most important part.

57. See John Dewey, "Fundamentals of the Educational Process," in Joseph Ratner, (ed.), "Intelligence in the Modern World," Random House (1939) pp. 622-3. Again it is useful to quote Dewey:

An authority...: he has pupils, is a "master" and not an advanced fellow worker; his students are disciples rather than learners. Tradition is no longer tradition but a fixed and absolute convention. In short, the practical difficulty does not reside in any antagonism of methods and rules and results worked out in past experience to individual desire, capacity and freedom. It lies rather in the hard and narrow and...uneducated habits and attitudes of teachers who set up as authorities, as rulers and judges in Israel. As a matter of course they know that as bare individuals they are not "authorities" and will not be accepted by others as such. So they clothe themselves with some tradition as a mantle, and henceforth it is not just "I" who speaks, but some Lord speaks through me. The teacher then offers himself as the organ of the voice of a whole school, of a finished classic tradition -[so that] suppression of the emotional and intellectual integrity of the pupils is the result.

58. Neil Postman and Charles Weingartner, "Teaching as a Subversive Activity," Delacorte Press, N.Y. (1969) p. 153. They suggest that "course requirements" are particularly insidious for they "shift the focus of attention from the learner to 'the course,' and...force the teacher into the role of an authoritarian functionary whose primary task becomes that of enforcing the requirements rather than helping the learner to learn." (authors' emphasis)

59. See F.L. Meijler, "Lottery Admission System in Netherlands," Science Vol. 187, No. 4172 (January 10, 1975):114. Even the superior student has about one chance in three of being selected.

60. J. Stamler (Chairman, Dept. of Community Health and Preventive Medicine, Northwestern University) has noted that for men there is a strong positive correlation between the quitting of smoking and measured IQ. However, for women (and nurses) the exact opposite is true. He suggests that this is a "very complex social phenomena." (Lecture at University of Iowa, May 1976.)

61. Thomas Stern, "Continuing Medical Education in America," J. Fam. Practice, Vol. 3, No. 3 (March, 1976) pp. 297-300.

62. Ibid.

63. Bernard Davis, "Academic Standards in Medical Schools," N. Eng. J. Med. 294(20): 1119-20 (May 13, 1976).

64. Michael Herring, "Medical School Minority Program Rap Sparks Indignation and Rue," Medical Tribune, 17(23):1, 46 (July, 1976).

65. As Einstein expressed it (regarding the automatic rejection of his ideas), "I learned many years ago never to waste time trying to convince my colleagues." (Reported by Cantril in H. Cantril (ed.), "Morning Notes of Adelbert Ames," Rutgers Univ. Press (1960) p. vii.")

66. See Postman and Weingartner's (op. cit., p. 17) comparison of McLuhan's "The medium is the message," with Dewey's "we learn what we do."

67. E. Lenneberg, "Brain Correlates of Language," in F. Schmitt (Ed.), "The Neurosciences," Rockefeller Univ. Press (1970) pp. 361-74.