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Generative Learning Processes of the Brain

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This article presents a functional model of learning from teaching that, in contrast to structural models of schemata and knowledge representation, focuses on the neural and cognitive processes that learners use to generate meaning and understanding from instruction. Wittrock's model of generative learning (Wittrock, 1974a, 1990) consists of four major processes: (a) attention, (b) motivation, (c) knowledge and preconceptions, and (d) generation. Each of these processes involves generative brain functions studied in neural research and generative cognitive functions studied in knowledge-acquisition research. In this model of generative learning, the brain is a model builder. It does not transform input into output. Instead, it actively controls the processes of generating meaning and plans of action that make sense of experience and that respond to perceived realities. Within this framework, teaching becomes the process of leading learners to use their generative processes to construct meanings and plans of action.

The model of generative learning and teaching (Wittrock, 1990, 1991) is a functional model of learning from instruction that builds upon knowledge about the processes of the brain and upon cognitive research on comprehension, knowledge acquisition, attention, motivation, and transfer. I first reported the model and its underlying empirical research in 1974 (Wittrock, 1974b). That beginning led to a line of experiments that examined and tested implications of the model (e.g., Wittrock & Carter, 1975; Wittrock, 1990). Unlike studies of the effect of generation of words that appeared later (e.g., Slamecka & Graf, 1978), research based on the generative model deals with the effects of generation of meaningful relations—among concepts and between knowledge and experience—on learning from teach-

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ing. These generations include and extend beyond the relations among individual words to sentences, large blocks of text, images, and procedures that characterize meaningful learning from instruction and teaching.

The model of generative learning differs from cognitive theories of the storage of information in several ways. First, the focus in learning is on generating relations, rather than on storing information. At the essence of this functional model are the generative learning processes that people use actively and dynamically to (a) selectively attend to events and (b) generate meaning for events by constructing relations between new or incoming information and previously acquired information, conceptions, and background knowledge. These active and dynamic generations lead to reorganizations and reconceptualizations and to elaborations and relations that increase understanding.

In this model, comprehension and understanding result from the processes of generating relations both among concepts and between experience or prior learning and new information. The teaching of comprehension involves the process of leading learners to construct these two types of relations across concepts and between prior learning and new information. This active generative process is quite different from the process of getting learners to store information for reproduction on lists.

On the production side, structural models focus on the processes of retrieval of information from memory. One result of that focus is a concentration of research on the memory structures that determine retrieval, with a consequent reduction of research on the processes that generate the information measured by the tests of memory. Unlike the purpose of many structural models of memory, the purpose of this functional model is to provide an understanding of the generative nature of comprehension that will lead to useful instructional applications that can produce sizable gains in learning from generative teaching in classrooms and in related educational and training settings. Instead of focusing primarily on the structural properties of knowledge, the functional model focuses on: (a) learning processes, such as attention; (b) motivational processes, such as attribution and interests; (c) knowledge creation processes, such as preconceptions, concepts, and beliefs; and (d) most importantly, the processes of generation, including analogies, metaphors, and summaries (Wittrock, 1990).

Another major difference between the model of generative learning and cognitive theories of structural knowledge is that the model of generative learning has been built upon neural research. Neural research on the brain informs cognitive models of learning and teaching, sets limits upon them, and makes them more educationally useful. For example, the two attentional components of the model – involuntary and voluntary – and the motivational component reflect research on neural models of arousal and activation in attention (McGuinness & Pribram, 1980) and related neuropsychological and cognitive research on attention and motivation (cf. Wittrock, 1980, 1986, for summaries).

A NEURAL MODEL OF GENERATIVE PROCESSES

For many years, neural research on attention and learning has demonstrated the generative nature of these brain processes, which function actively and dynamically to construct meaning and to interpret experience, rather than passively to receive and record incoming, sensory information. McGuinness and Pribram (1980, p. 101) wrote "behaving organisms are spontaneously active, generating changes in the environment." Elio Maggio (1971, p. 81) wrote:

> As matter of fact, it has been proven that input signals can be modified in the brain even before they reach the specific sensory areas of the cortex, and that this alteration of sensory stimuli is due to the prewired organization of the nervous system of each individual but is also significantly influenced by learning experiences. Experience, in other words, molds neurophysiological mechanisms, even those which appear more stable and closely depending upon genetic and biochemical factors. The central nervous system is not only the site where passive interconnecting functions occur, but also, and perhaps primarily, a structure allowing an active function upon varied incoming sensory stimuli.

Luria's (1973) first of three functional systems of the brain involves arousal and attention. These processes are influenced by the cortex and by conceptually driven behavior via the descending reticular activating systems, as well as by metabolic and external sensory stimuli mediated by the ascending reticular activating system. In other words, the plans and intentions of the learner, which are mediated by the frontal lobes of the cortex, influence the attentional and motivational processes of the brain, and consequently, the stimuli we attend to and the level of activity we devote to those stimuli and their meaning.

The evoked-potential (EP) technique and the event-related potential (ERP) method clearly show the importance of attention in understanding learning and learning disorders among children (Languis & Wittrock, 1986). For example, poor readers with normal IQs sometimes show more of a deficit (i.e., a lower brain-wave response) than do other readers to light flashes, but not to words, at 200 msec latency, which indicates an attentional deficit rather than a deficit in the ability to read words. In addition, extensive series of research on hyperkinetic activity have shown the utility of attention in explaining many cases of hyperactivity (cf., Wittrock, 1986, for a discussion of this research). Attention and motivation seem clearly established as important generative processes of the brain for active selection of stimuli and regulation of the process of constructing meaning from events.

The third and fourth components of the generative model of learning involve the use of knowledge-creation processes in the generation of meaning from instruction. Neural research also directly contributes to an understanding of these generative processes of the brain.

Luria's (1973) second of three functional brain units—the unit for receiving, analyzing, and storing information—codes and integrates information from all of the senses. This unit, like the arousal and attentional unit, receives signals from the frontal lobes that mediate plans, programs, and organizations and that inhibit alternative reactions and interpretations. Within this second functional unit of the human brain lie the verbal and spatial, propositional and appositional, and analytic and holistic generative brain mechanisms for learning and understanding information. (Luria organized these processes differently—into simultaneous and successive strategies.) The voluminous research on these brain processes, pioneered by Sperry (1968) and his students and colleagues, including Bogen (1977), Gazzaniga (1977), Nebes (1977), Trevarthen (1980), and Levy (1980), cannot be adequately summarized here. Their neuropsychological research on the learning processes of the brain has influenced research in cognitive psychology, models of intelligence, and educational psychology and has emphasized the generative nature of learning. For example, research on the hemispheric processes of the brain supports a generative conception of learning in which meaning is constructed in multiple ways by organizing stimuli into coherent sequences and patterns that reflect the learner's knowledge and experience. (For further discussion of research on these analytic and holistic processes using the ERP method, see Languis & Wittrock, 1986.)

Luria's third functional unit of the brain, the unit in the frontal lobes for planning, organizing, and regulating cognition and behavior, functions as a generative processor and as the integrator of the brain's generative functions. The intentions and purposes of the learner play central roles in determining motivation and arousal, in selectively attending to events, and in generating meaning for these events by relating them to knowledge and experience. The coordination of all these generative processes of the brain by this unit for planning, organizing, and regulating thought and action represents a critical part of the generative activity of the brain. These metacognitive activities reflect higher order, sophisticated generative processes that influence the construction of meaning and that integrate and coordinate the generative processes of attention and arousal, motivation, and learning.

In those ways the model of generative learning incorporates neural research findings about the brain processes that create the cognitive and behavioral functions we study in educational psychology. Educational psychological phenomena cannot be reduced to neural events. But neural research can identify and inform us about the fundamental generative processes that function in complex educational contexts, putting limits upon the cognitive and behavioral models we use to understand and to improve learning from teaching. In that sense I have constructed the model of generative learning to be consistent with research on the functional processes of the brain.

In another, more intuitive sense, I have constructed this cognitive model to be a theory of generative brain functioning, rather than an information-processing model of memory. Neural systems of the brain do not function in the same way as many other biological systems. Neural systems do not transform inputs into outputs, as, for example, digestion does. On the contrary, neural systems control other biological systems. Neural systems show self-direction, self-control, motivation, and arousal. They receive, selectively attend to, and integrate multisensory information. They relate multisensory information to knowledge, experience, intentions, and purposes, all of which are sources of control that regulate the construction of meaning. From this synthesis, they generate meaning and significance. They also involve metacognitive activity. They construct context-specific learning strategies and plans that regulate motor responses and that adapt to a perceived and constructed reality. They learn, and they modify their future operations. They do not passively receive and record information. They are generative systems.

The brain generates models. Its primary function is to generate a model, or models, that enable us to make sense of the many events we experience. These models have great survival value. They lead to an understanding of why things are happening. Understanding leads to predictions about what we can likely expect to happen in the future, and, most importantly, about how we can exert some control and direction over that future.

Related Research

The model of generative learning is compatible with related cognitive, neuropsychological, and connectionist research, which represent different levels of the same phenomena studied at a neural level. From cognitive research on knowledge acquisition and comprehension (Wittrock, 1981) we understand that learning is not the internalization of information given to us whole by experience or analyzed by a teacher. Instead, learning consists of the active generation of meaning, not the passive recording of information. The model of generative learning builds on this conception, which is quite compatible with recent neural research.

From one line of cognitive research, schema theory (e.g., Rumelhart, 1980), we have learned much about the structure and the representation of stored information. Schemata store general information; scripts store specific experience. However, schema theory informs us less about cognitive functions. Schema theory implies only that learning involves slotting new information into schemata, or relating new information to scripts. In brief, this line of research informs us well about the structure of memory and learning, but it informs us much less well about how learning occurs and how teaching can be facilitated.

The model of generative learning is a functional model of the kind proposed by Iran-Nejad (1989; Iran-Nejad & Ortony, 1984). These types of models emphasize research and theory about the functions of cognitive and neural systems involved in teaching and learning. To improve teaching and learning we need to know not only the structure of information, but how meanings, inferences, and understandings are generated, and how relations among concepts and experience are constructed.

Perhaps only dynamic "generator sets," (fundamental units that can be combined into larger units) along with instructions that regulate them, are used. From these generator sets, our structures and schemata, memories and episodes, are instantly generated when they are needed. Much of what we have learned indicates that learners do not store information verbatim and that memory reflects mood, context, and intention at the time of recall. We need to examine carefully the concept of "storage." Perhaps we need a better concept. That possibility fits my model well.

Recently, we have acquired connectionism, which presents an associationistic, subconceptual model of memory whose nodes and connections do not represent single concepts as they do in cognitive or so-called conceptual, or symbolic, cognition models (e.g., Smolensky, 1988). Instead, a connectionist model distributes memories over a network of associations. A memory, then, consists of a pattern of associations within a network of nodes and connections; other memories or ideas can cross the same nodes and connections by varying the patterns or the weights of the units in the system. Within this conception, learners acquire concepts and nodes indirectly and inductively by averaging weights of repeated experiences of similar events.

By contrast, a symbolic cognitive model (e.g., a structural schema model) emphasizes the learning of rules involving schemata, scripts, and plans. This difference in conception reflects the ancient debate between Plato's emphasis on the priority of forms and abstractions and Aristotle's focus on the induction of concepts from commonalties across particulars. The connectionists enter this venerable debate by suggesting that relations between environments and actions consist of patterns in networks that are activated in parallel. These networks are subconceptual, and neurally inspired, but they are not neural units. In other words, the connectionists believe that the subconceptual level, not the conceptual level, represents the most scientifically useful level of study.

In my attempts to construct a model of generative learning from teaching, I have avoided selecting research at one level of study over another. Instead, because these levels study the same phenomena in different ways, I have chosen to look for their complementary findings, for agreement across the levels of research.

RESEARCH ON THE MODEL OF GENERATIVE LEARNING

The model has been studied in a variety of studies in schools and in laboratories on the teaching of reading comprehension (Doctorow, Wittrock, & Marks, 1978; Linden & Wittrock, 1981), mathematics (Peled & Wittrock, 1990), science (Osborne & Wittrock, 1983), and economics (Kourilsky & Wittrock, 1987). In one experiment on reading comprehension and retention (Wittrock & Alesandrini, 1990), students generated either analogies or summaries as they read a high-imagery text, a chapter from Rachel Carson's book *The Sea Around Us.* A control group read the same text without constructing either analogies or summaries. From the generative model, we predicted and found that (a) only holistic-imagery ability correlated with reading performance in the control condition, (b) only verbal-analytic ability correlated with reading performance in the analogies condition, and (c) both holistic–imagery ability and verbal–analytic ability correlated with reading in the summaries condition. In addition, as predicted, the summaries condition produced the highest mean reading score (29.8) followed by the analogy condition (27.2) and the control condition (22.4). These predictions of the generative model were based on the complementary neural and cognitive research that indicates that analytic-verbal and holistic-imagery process are two important systems used by the brain to construct meaning for information, such as text. Table 1 summarizes these findings.

In a study of high school students learning economics (Kourilsky & Wittrock, 1987), we predicted and found that the learning of abstract verbal concepts would be enhanced by the use of graphs to teach abstract verbal relations among concepts and variables.

In a study of 50 protocols of sixth graders, Peled and Wittrock (1990)

TABLE 1
Means, Standard Deviations, and Correlation Coefficients for the Learning and Ability Scores

	Treatments		
	Generate Summaries	*Generate Analogies*	*Read Text*
Learning[a] (72 items)			
M	29.8**	27.2*	22.4
SD	7.7	6.3	9.2
Abilities			
Verbal-Analytic			
Mean	16.6	18.0	16.9
SD	4.0	3.2	2.8
Spatial-Holistic			
Mean	8.4	7.5	8.2
SD	2.2	2.6	2.0
Generations (100 maximum)			
Mean	98.7	75.4	
SD	2.4	23.3	
Correlations			
Learning and Verbal-Analytic Ability	.44[b]	.37[b]	.04
Learning and Spatial-Holistic Ability	.62[c]	.04	.47[b]

Note. From "Generation of Summaries and Analogies and Analytic and Holistic Abilities" by M. C. Wittrock and K. A. Alesandrini, 1990, *American Educational Research Journal, 27,* p. 496. Copyright 1990 by the American Educational Research Association. Adapted by permission.

[a]$n = 19$ for all treatments. [b]$p < .05$, different from Read Text. [c]$p < .01$, different from Read Text.

$^{*}p < .05$. $^{**}p < .01$.

found that two types of cognitive processes were involved in comprehending and solving word problems in mathematics. The first was a schema-reproducing process that involves construction of relations among mathematics concepts. A second was a story-generation process that involves the construction of relations between the learners' experiences and the mathematics concepts. The model predicted these two types of relations to be important for comprehension.

Doctorow, Wittrock, and Marks (1978) taught reading comprehension to sixth graders. The learners generated summaries for each paragraph of a story. To construct the summaries, the students had to use their own words to develop relations across the sentences of the paragraph. We designed that procedure to engage the processes of generating relationships, predicted by the model to facilitate understanding. The learners were not allowed to use or to modify any sentence in the text. Each summary had to be written in their own familiar words. That procedure produced nearly double the reading comprehension of a control group given the same amount of time to read the same stories.

In this study, the predictions of the model were supported. The data indicated the importance for comprehension of teaching students to generate relations (a) among text concepts and (b) between concepts in the text and the learners' experiences. The distinctive type of summary we asked them to generate facilitated construction of these two types of relations and of comprehension.

When these same generative procedures were used in classroom studies to teach reading comprehension to functionally illiterate young adults at several locations in California and Hawaii, gains of 15% to 20% were regularly found after 10 days of instruction (Wittrock & Kelly, 1984). With this more difficult problem, the model again led to useful instructional methods. The teaching procedures again produced statistically significant gains in comprehension (see Table 2).

We have applied the model to other problems of reading comprehension (Linden & Wittrock, 1981; Wittrock, Marks, & Doctorow, 1975) and science learning (Osborne & Wittrock, 1983, 1985). All these studies support a view of learning with understanding as a generative process and encourage further research into the functional properties of generative learning, as they relate to teaching and instruction.

TABLE 2
Means, Standard Deviations, and Gains in Reading Comprehension of the Experimental and Control Groups of Functionally Illiterate Young Adults

Treatments	*Pretest*	*Posttest*	*Gain*	*t*	*Level of Significance*	*% of Gain Over Pretest*
Summaries, Headings, & Inferences Strategy[a]	18.9 (4.1)	22.6 (3.9)	+3.7	5.9	$p < .0001$	19.6
Metacognitive Strategy[b]	20.5 (3.6)	23.1 (4.2)	+2.6	4.2	$p < .001$	12.7
Metacognitive Examples Strategy[c]	17.9 (5.7)	22.1 (4.6)	+4.1	6.7	p < .0001	22.9
Control Group[d]	21.1 (5.4)	20.8 (5.4)	−0.3	.4	ns	—

Note. From *Teaching Reading Comprehension to Adults in Basic Skills Courses* (final report), by M. C. Wittrock and R. Kelly, 1984, Los Angeles: University of California, Graduate School of Education.

[a]$n = 29$. [b]$n = 26$. [c]$n = 29$. [d]$n = 16$.

SUMMARY

A variety of empirical studies on reading comprehension, mathematics learning, science learning, and economics teaching show the utility of a functional model of generative learning, in which the brain actively and dynamically constructs meaning by building relations. Unlike many structural models of memory and storage that often have few instructional implications, this functional model of generative learning leads to the design of effective instructional procedures that often produce sizable gains in comprehension and understanding.

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