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TOWARD A SCIENTIFIC BASIS FOR THE CRAFT OF TEACHING

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Abstract

This study develops a hard systems model for learning that differs from traditional or intuitive models. Research in educational psychology and cognitive science provides the basis for the model. The paper also presents a traditional soft system view of the craft of teaching. Perception, memory, and concept formation are presented as the essential ingredients for effective learning. The systems models for learning and teaching are defined and contrasted, and instructional implications are discussed. Agricultural educators teach; they train prospective teachers, and they offer inservice to practicing teachers. This is education. These educators have historically spent the majority of their research and instructional time studying and teaching the craft of teaching. University professors, who may or may not have had any formal teacher training, practice the craft of teaching. This paper presents a review that moves toward a scientific basis for the craft of teaching.

"Effective teachers draw on a growing body of research knowledge about the nature of learning and on craft knowledge about teaching that has stood the test of time" (Project 2061, p.197). Learning is the reception of new information, its retention over a period of time, and its subsequent recall. To understand learning, we must consider how new information is received; the stages through which new information is processed as it progresses from immediate sensory experience to long term storage; the organization, analysis, and encoding that takes place along the way; and its retrieval.

Teaching is the organizing, planning, delivering and evaluating of that which is to be taught, for those who are to be taught. To understand teaching we must understand the organization and structure of subject matter, characteristics of the learner, presentation skills, and evaluation techniques.

Teacher educators have historically spent the majority of their instructional time studying and teaching the craft of teaching. University professors, who may or may not have had any formal teacher training, practice the craft of teaching. This study presents a 'soft systems model' for the craft of teaching and develops a 'hard systems model' for the science of learning, contrasting the models and offering implications to practice.

Traditional research methodologies are often not applicable when studying human activity systems such as teaching and learning. Systems approaches to inquiry are appropriate to the purposes of this study (Wilson and Morren, 1990). Systems scientists study the structures and functions of some system, identify levels of organization of the system, and attempt to understand how the system connects vertically and horizontally (Holt, 1988). The tools used by the systems scientist are models: the process is called modeling. Alcorn (1986) describes the modeling process as: 1) gather information about the concept or physical structure to be modeled; 2) based on this information, reach conclusions about the nature, characteristics, and behavior of the reality to be modeled; 3) determine an appropriate form for the model; the degree of detail required; what elements are important in understanding the nature of the reality; and, of those elements, which should be included in the model itself; 4) build the model; 5) compare the model with reality to determine the degree to which the model actually approximates the reality; and, 6) adjust the model as necessary to achieve the desired fit.

A model represents knowledge about the system. The model is considered valid when it describes the behavior of the system. The modeling process is iterative; the model itself may be as dynamic as the system being modeled.

Soft Systems Model of Teaching

In a working session of the Fourth National Conference on Training and Employment of Graduate Teaching Assistants (Buriak and Harper, 1993), teacher educators and discipline-based graduate teaching assistants were instructed to construct a model (concept map) of teaching. The results of this activity are shown in Figure 1 and Figure 2. The figures indicate teaching as a soft systems model. A soft systems model may be defined as a set or sets of purposeful human activities. "While the basic components of human activity systems are drawn from a universe of real, observable attributes, it is up to the observer . . . to select the activities assigned to a given human activity system" (Wilson and Morren, p.106).

Teaching affects student achievement, it varies according to content, it interacts with the characteristics of the learner, it is affected by classroom climate, and it is done by teachers. The teachers organize, plan, deliver and evaluate based on their beliefs, values, culture and experiences. The students/learners interact with the teachers and the content domain. This interaction is impacted by the students' beliefs, values, culture and experiences.

Learning is a human activity intrinsic to the learner. Learning is not necessarily an outcome of teaching. The teaching-learning paradigm is not causal. Cognitive research demonstrates that even when exposed to seemingly good instruction, many talented students actually understand less than would be expected. Careful probing often shows students understandings are limited, distorted, or, in fact, wrong. . . while teachers believe they have effectively organized, planned, and delivered the lesson. This would imply that mastery of the craft knowledge of teaching may not be enough to be a truly effective teacher. The soft systems model of teaching can not effectively stand alone.

Hard Systems Model for Learning

Our approach is based on current thinking in cognitive science. In developing the model, its precursors had to be reviewed. For most of this century psychologists and teachers have been influenced by behaviorism; the belief that human behavior can be *controlled* through punishments and rewards. This theory can be described by the formula S-->R, or stimuli cause responses, implying that we are driven entirely by our environment. There are many reasons for the lack of support behind a behaviorist theory. Braune and Foshay (1983) explained that when designing training, it is often difficult to define a criterion which truly indicates readiness for successful integrations with the actual task domain. Complex environments [like teaching] make it virtually impossible to predict, train and test all permutations of all possible conditions. In other words, we can only represent or explain a finite number of stimuli; certainly not all that might be having an impact, or controlling the human behavior called learning.

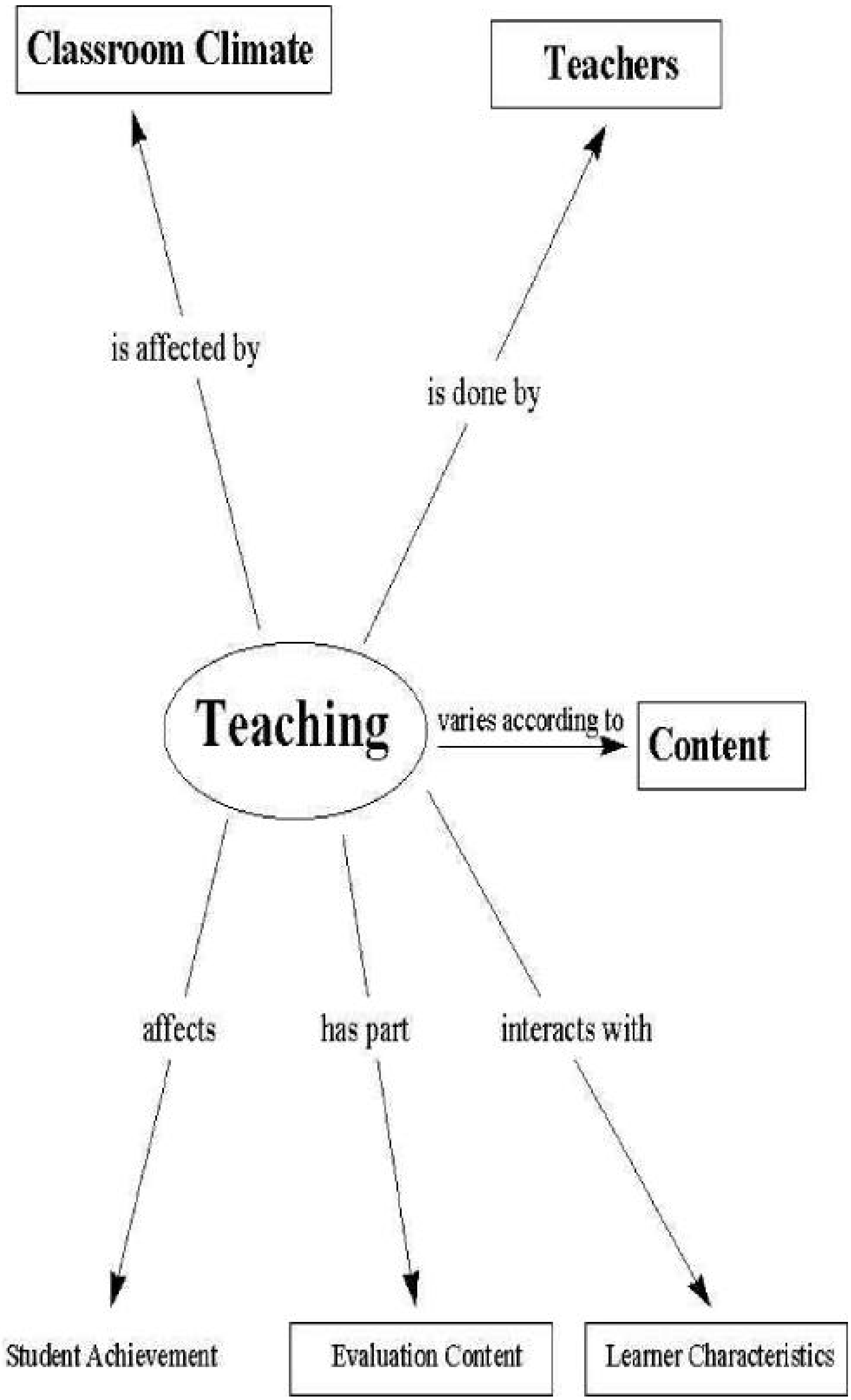

Figure 1. Teaching as a system: The parent model.

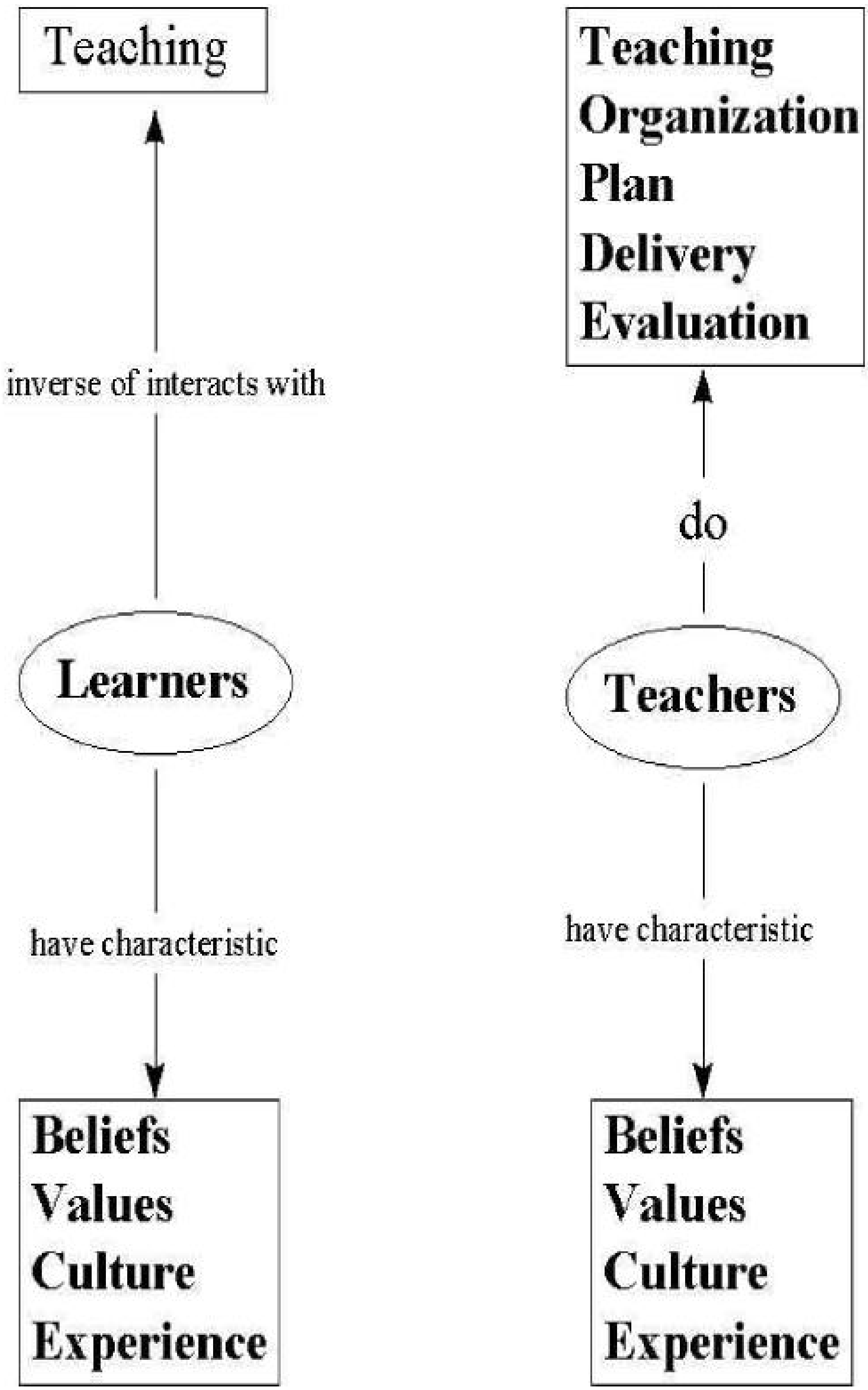

Figure 2. Teaching as a system: Soft systems model

Much of the work in cognitive psychology focuses on the notion that the acquisition and retention of new behaviors and new knowledge is a function of existing cognitive structures within the learner (Merrill, Kelety, & Wilson, 1981). One of the earliest proponents of this view was Ausubel (1968). He argued that new material is acquired to the extent that it can be meaningfully related to, or *subsumed* under broader categories of previously learned information. Current cognitive theories of learning, like Ausubel's Subsumption theory, focus on the information processes and structures which are involved in learning new information.

These new cognitive theories have a considerable role in education. As students (novices) collect new sets of stimuli and process and store them, their brains are in a constant state of change. The new connections that they make enhance their abilities. Without the capability to make new connections, certainly students would not be able to learn a new language, a new computer program, a difficult concept in physics, or simply the location of the nearest grocery store. However, a correlate of producing new connections in brains within the rewiring analogy is the degeneration of neural connections, or pruning. On occasion, even at a surface level, it is beneficial to remove irrelevant data or fuzziness rather than adding new information. Perception and critical thinking are the two proprietors of selecting and pruning.

When students set out to learn a new skill, they do so with a direction and a purpose in mind. It may not be stated formally in rules or goals, but it is implicit in the manner by which we engage in behavior. New connections and a pruning of the old takes place, often haphazardly. As educators we often encounter such trial and error behaviors in our students. For example, we may provide the protocols that are necessary to solve a particular problem, fully expecting the students to make connections and follow steps that we as experts would take for granted. Contrary to this traditional view, novices do not solve problems the same way that experts do. For example, experts and novices typically apply physics principles in just the opposite order. Novices start out with productions for reasoning backward and slowly develop productions that make forward inferences. Reasoning backward involves setting goals and subgoals and keeping track of them. This puts a severe strain on working memory and can lead to errors. Experts move in the opposite direction, moving forward. There are real advantages to forward reasoning in domains such as geometry and physics. Reasoning forward eliminates the need to keep track of subgoals. However, to successfully reason forward, one must know which of the many possible forward inferences are relevant to the final solution. This is what the expert learns through experience. The expert learns to associate various inferences with various patterns or features of the problem. Experts also have the added benefit of increased long-term memory within the domain of expertise.

The process of systematic schema-building for problem-solving occurs in many disciplines. Expert teachers use parts of the old curricula and build upon it. Teachers and instructional designers rarely if ever start from scratch when creating a learning activity. They build on techniques that have worked in the past and apply them in novel ways. We can also see from the student's perspective that learning is a building process that is a more randomized than random. In the acquisition of knowledge, students gather new information and build it into their already existing schemata. Even the manner in which students rummage about for data is a schema-building, critical thinking procedure. This process schemata, or plan for acquiring knowledge, improves over time, changing with the needs of the student. Theories that work are held onto for a time, until a more effective theory comes along. Learning is more analogous to building a tower, constructing it with bits and pieces of other structures which were sturdy in their day but have now outlived their usefulness.

The transfer of knowledge from the base domain to the target domain depends a great deal on goodness of fit. The more similar the two domains the easier and more efficient the transfer of information. As experts in systems management, we tend to generate variability in our analogies and at the same time are able to recognize similarities across a greater array of content areas. This variability, although not readily apparent, does exist in the system, or else how would we continue to come up with novel ways of describing new concepts to other individuals or groups?

What we have been discussing, the process of learning, can be distilled to simpler components. Learning consists of basically three tasks: accretion, tuning, and restructuring (Rumelhart & Norman, 1978). The amount of time we spend in each of these tasks varies across all individuals and according to the qualities of the knowledge being acquired. We spend proportionally a much greater amount of our time in accretion, a little less in tuning, and much less in restructuring. The structure of the knowledge domain we happen to be interested in also dictates how we will allocate our time and energy in these tasks as well. Accretion, tuning, and restructuring within every individual uses perception, memory, and concept formation. These three qualities are specific to each learner and vary, although minutely, in skill level from one learner to the next (see Figure 3).

Accretion is that process of importing knowledge into an already existing concept or schema. No change needs to be made to the schema because the structure is capable of enveloping the new information in its current state. For example, when an experienced farm mechanic takes a 100-level machine course, most of the information she will be exposed to will be put into an already existing schema of mechanical knowledge. Tuning consists of revising the old schemata in order to acquire the new knowledge. When a food engineer goes to a 2-day training seminar on MathCAD, his primary task will probably be tuning. He already has many established schemata for mathematics but the technology might require him to change some of these. Restructuring, the most difficult of the three processes, occurs when it is necessary to modify the schemata so severely that they are unrecognizable. They are new schemata. On a young child's first visit to the zoo, many new schemata will need to be created, where perhaps only the dog and cat (animal) schemata existed before.

Schemata, or what we call concept formations, are the bundles of knowledge that are not only created through our experiences but shape our later experiences as well. We can say that our schemata direct our perception (Rumelhart & Ortany, 1977). For example, when people visit the art museum they see very different things. A child perceives something, an adult perceives something else; the art historian perceives something, an engineer perceives something else. How we encode data is largely dependent on the concepts or schemas we have formed in the past.

When we are presented or exposed to new information we cannot always know what schemata will be activated and which parts of the event will determine the meaning that we derive from the new information. This is impossible for the learners themselves to predict; it is clearly beyond the power of teachers. This is only one contributing factor to our inability as educators to draw a clear connection between teaching and learning. We cannot predict with much certainty how the information in our presentation will be received and connected to the learner's store of experience (Vosiadou & Brewer, 1987).

Cognitive scientists have reconceptualized perception and learning. No longer do we say that data are received by the learner and regurgitated at a later time; instead we say that perception, concept

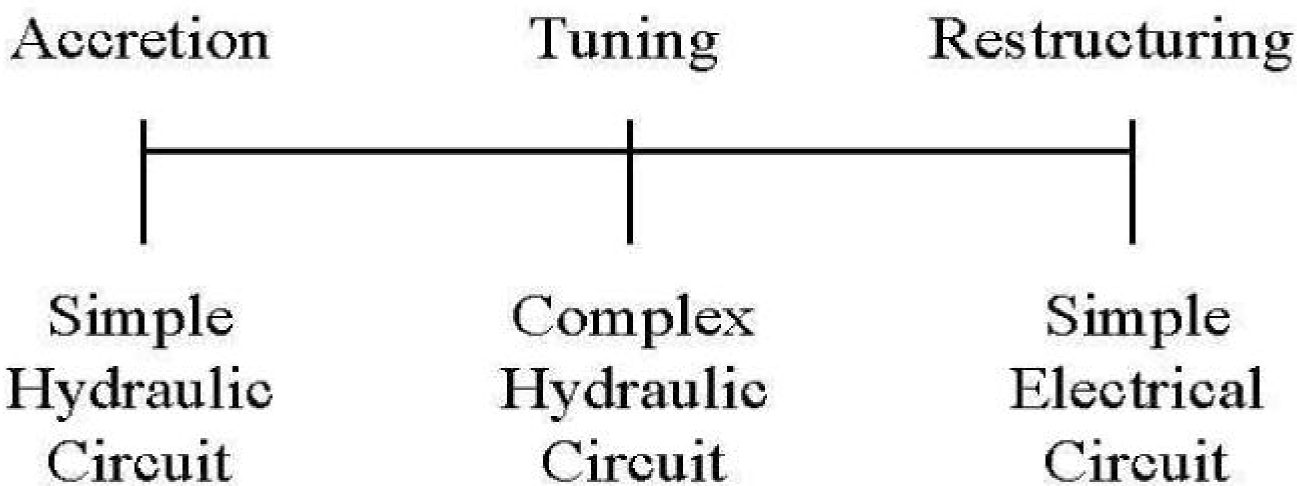

Figure 3. Accretion, tuning, restructuring.

formation and memory interact to produce learning. Figure 4 shows a hard systems model for learning.

Learning is contingent upon perception. It improves concept formation-- the essential element of human thought. Learning is benefited by memory and is achieved through thoughtfulness and critical thinking. Learning is a process that occurs when a person gains abstract knowledge to apply across contexts. In addition, the person acquires the skill to perform and use this knowledge by actually engaging in the process, participating in the actual practice of an expert, but only to a limited degree and with limited responsibility for the final product.

Think of an apprentice who is learning to shoe a horse. The experienced blacksmith may instruct the novice apprentice to work initially with a shoe and a mock-up of a real horse. After much practice the apprentice would one day be allowed to shoe a real horse. When an instructor sets up the process with intermediate steps like this we call it scaffolding. Also note the apprentice learns not only by observing the blacksmith but by engaging in the process.

Learning involves several important factors that should be understood by both the learner and the instructor. Perception, memory, and concept formation are all critical factors for learning and are entities that are entirely under the control of the learner: Instructors can exert no control over these three. What instructors do may influence how learners use them, but they can never have direct control.

Perception is the selective process that occurs continuously through multiple modalities (i.e., hearing, seeing, touching). Data are collected and are stored in memory as schematic entities. In order for learners to perceive something, they must be attending to it. Psychologists have learned a great deal about what people pay attention to, but individual differences also exist. Only what people perceive can be stored in memory. For example, when college professors present an abundant amount of visual information to their students during lecture (either through transparencies, computer shows, or the chalkboard), and at the same time lecture or provide aural information, much of what is presented can be lost. The students will only be able to pay attention to pieces of the whole, which is why it is often best for instructors to make several "passes" through the material in order to allow for each learner to perceive all of the information.

Memory, specifically long-term memory, is an infinite storage space that holds all the data that a person has been exposed to or has experienced. The important mechanism in memory that relates to learning and performance concerns the integration and retrieval process of information. Getting information into memory has more to do with perception. If data are stored or organized appropriately, then it can be used in varying settings or contexts.

We are all genetically programmed with basically the same kind of memory apparatus. George Miller (1956) proposed that all normal adults have the capability of holding seven bits of information in short-term memory, plus or minus two. What this means is that for a very short period of time we can hold information, like a phone number, in our heads but we will remember it only if we actively process it. After only a moment it will be gone. So with a phone number, which happens to be seven digits, we break it up into parts-- six-zero-eight (pause), nine-two-nine-two. We may also attach it or pair it with a name, preferably the name of the person who lives at the address in accordance with that phone number. The phone number might also be similar to a phone number of another person who we know, so we

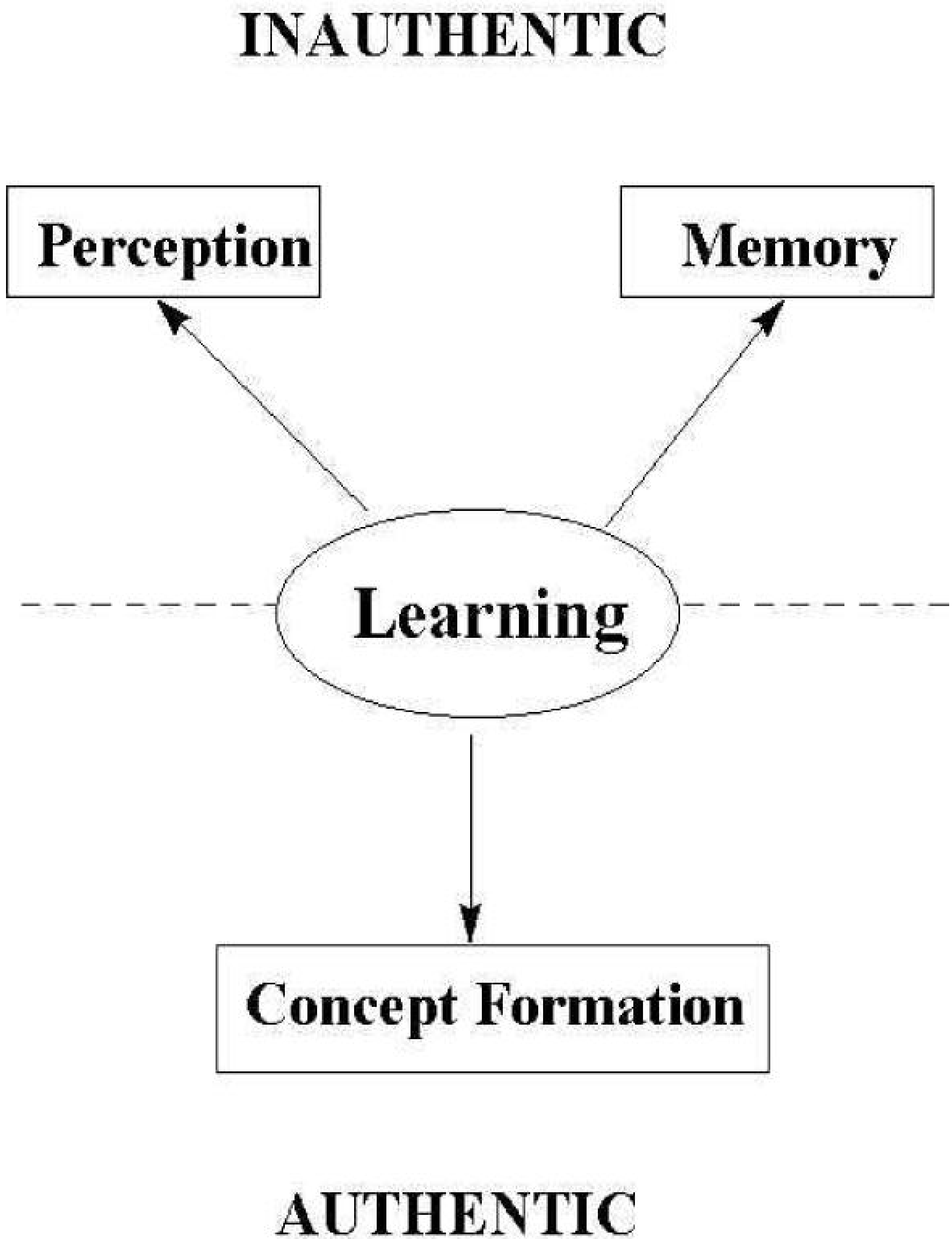

Figure 4. Learning as a system: The parent model.

make that association. All of these strategies are known as chunking strategies. These help increase the probability that we will be able to recall that information when we need it. Chunking is a tool we use to accomplish the formation of concepts, a higher-order form of thinking.

Concept formation involves the creation of a set of skills or schema that can be transferred to different contexts. More specifically, it involves the continual process of fine-tuning a network of skills through the progression from *novice to expert*. As learners go through the process of perceiving and chunking, they build larger and larger concepts, ultimately to the point where an expert has a very complex system of interconnections and clusters.

Concept formation is similar to surfing the Internet. When we start at a home page we see that there are links to other places on the Internet. These links are not placed there haphazardly; they are there because they are related to the topic of that home page. When we follow a link we take it to a page where we will find more related links, and so on. If the Internet were human we would say that it is learning.

As learners go through the process of forming and connecting concepts, they are thinking about the purpose of the information. The way in which the information will be applied is inextricably tied to the quality of the concepts formed. Thinking about applicability and purpose is called thinking critically. Critical thinking is a label for that type of thinking that involves the full integration of information into existing schema. Concepts are not learned for an inauthentic purpose, but for performance or application to a real, authentic context. Critical thinking does not include the sort of thinking that is surface-oriented or is learned for an inauthentic purpose (i.e., taking tests).

When learners are not given a purpose for learning or not allowed to find a purpose on their own, the quality of learning is suspect. Often learners spend a great deal of time processing information in order to recall it at later date for an exam, but that is a different process than if they were learning information to apply to a real task. In other words, learning information for an exam does not mean that the information is also being learned in order to be applied in other contexts. The best way for learners to learn how to use knowledge in multiple contexts is to have the experience of applying knowledge in multiple contexts. Clearly there are no short cuts.

Implications for Teaching and Teacher Education

Concept formation is the soul of learning. For learning to successfully occur, it must be purposeful and applied. Information gained by rote is not authentic. Mental processing must occur for linkages to be made and concepts to be modified or developed. Agriculture teachers and teacher educators must apply knowledge in multiple contexts to real situations before concepts will be formed and learning will take place.

Since concepts are modified and/or developed within the framework of past experiences of the learner, evaluation of learning should shift to a more formative model rather than the current emphasis on a summative model. Educators must know that the correct concepts have been learned, rather than some bastardized concept due to confounding from learners' past experiences. This is not meant to imply that summative evaluation should be eliminated; summative evaluations should shift emphasis to higher order cognitive processes.

Lesson development must move from compartmentalized, content driven models, to authentic, application based concept forming models. This applies to both agriculture teachers at all levels and agriculture teacher educators. As example, teacher educators teach the craft of teaching/the mechanics of teaching (methods, media, etc.). This craft instruction alone can be insufficient and may be inauthentic. Concepts of effective learning are complex and dynamic, not compartmentalized, and must be authentically developed in real situations for prospective teachers. Many teacher education programs graduate new teachers with less than 20 hours of real concept forming teaching experiences under "master tutelage," outside of student teaching.

The marriage of soft systems thinking and hard systems methods for instruction in the agricultural sciences and agricultural education is essential. This means the sciences must address the human activities surrounding the science and that education must look to science to explain learning. Hard and soft systems methods must be integrated if authenticity and valid conceptual formations are the desired outcomes of instruction. Education is an applied science (a craft) that has evolved from soft systems methods of inquiry. Cognitive science has forced the integration of hard systems methods of inquiry (a method of science) into educational research, theory and practice. The result is a scientific basis for the craft of teaching. Agriculture and its related disciplines are applied sciences that have evolved from hard systems methods of inquiry. Social, cultural, and ethical pressures have forced the integration of soft systems methods of inquiry (a method involving human activity) into research and practice in the agricultural sciences and their management. The result is a holistic view of problems in the discipline. Agricultural education has evolved from soft systems methods of inquiry. An understanding of both hard and soft systems methods of inquiry directed toward teaching and learning research may lead to improving our students' ability to think critically and effectively solve higher order problems.

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