Reflections on a Four-Decade Search for Effective, Efficient, and Engaging Instruction

M. David Merrill

Merrill, M. D. (2008). Reflections on a four decade search for effective, efficient and engaging instruction. In M. W. Allen (Ed.), *Michael Allen's 2008 e-Learning Annual* (Vol. 1, pp. 141-167): Wiley Pfieffer.

Summary

In this article, the author chronicles his career, from his interest in making education more effective to an epiphany about theories. His extensive experience with computer-assisted learning spans from early efforts to teach concepts to more recent work with automated authoring systems. His recent work attempts to identify underlying principles common to most theories of instruction. The author suggests that there should be less emphasis on merely conveying information using technology and more emphasis on how to make instruction effective, efficient, and engaging.

The Beginning

This article is a very autobiographical account of my career. Perhaps my personal quest for understanding the nature of instruction will be instructive to those of you who are also pursuing this important question. While I have learned much I have also realized that there is much more to learn. If I had a wish, it would be to be able to begin my career again while retaining what I have learned.

From July of 1957 until July of 1959 I found myself in Indiana, Ohio, and Michigan, where I served as a missionary for the Church of Jesus Christ of Latter-day Saints. Some of our missionaries were very effective teachers; for others, their attempts to share our message was an embarrassment. I determined that when I returned from this experience, I would change my major from engineering to education so that I could learn how to be an effective teacher.

My major in secondary education was a frustrating experience. While I learned how to minimize liability, how to create a resource file, how to pass out papers with a minimum of confusion, and other necessary skills for a classroom teacher, I can only recall one or two lectures that dealt with the topic of effective instruction. I had a wonderful experience as an unconventional student teacher but caused considerable consternation for the principal of the school where I was assigned. I was advised that I probably would not survive the public schools. It occurred to me that perhaps my decision to major in education was a mistake and that I should seek another career path. As I expressed my frustration to one of my professors, he gave me a challenge that put me on the career path that I have since pursued. In response to my suggestion that I abandon education, he simply stated, “You could pursue another career, or you could realize that there is much that needs to be done. Perhaps you could make positive change in the field.” He suggested that funding was available to pursue a PhD. Not being one to back away from a challenge, I decided to take up the gauntlet. Applications to several major universities resulted in a full-ride NDEA three-year fellowship to the University of Illinois.

In my final semester of undergraduate work, a check with the registrar showed that I was short one hour of credit for my minor in mathematics. Naturally there was no one-hour math classes, so it was necessary to enroll in a three-hour class. The University of Illinois had already awarded me a fellowship for my Ph.D. study, therefore the completion of the additional math class assumed considerable significance for my future. A class in number theory appeared, on the surface, to be the easiest path to the necessary credit. The year was 1961. New mathematics in the public schools was still in the future. Computers were just coming on the scene. Binary arithmetic, base 8, base 16, and other representations of numbers were not in the repertoire of a small-town undergraduate student scrambling to complete his bachelor's degree.

This particular class in number theory was, for this student, a unique math class: no problems to work, no homework, a very small textbook. At the end of each lecture the professor merely said, "Think about it!" Think about what? How do you think about mathematics? In desperation, and as a substitute for thinking, I read the textbook every week. It wasn't difficult; it had only 97 pages and a bright yellow cover. However, the concepts presented floated over my head like clouds in the sky. I had no idea what the course was about or what the text was about. Each week a lecture, the injunction to "Think about it!" and another read through the text.

The midterm exam was a disaster. It had no problems to work, only a single question: "Invent a number system." Invent a number system? What in the world does that mean? In true survival mode I wrote for the whole two hours. However, it didn't fool the professor. There were seven students in the class; there were seven F's on the midterms. When we objected, the only explanation from the professor was, "Think about it!"

My anxiety was at an all-time high. My graduate career was about to be terminated before it began by the unnerving command, "Think about it!" I tried every avenue of escape: Another class? Getting the registrar to waive the credit? Home study? There were no other options. My bachelor's degree, and hence my entrance to graduate school, were both riding on a class in which I had received a failing grade on the midterm and, worse, a class that was to me completely incomprehensible.

Somewhere in the thirteenth week the light came on. Number systems are inventions. They are not natural phenomena. Number systems are like any other invention: an assembly line, an organization. A number system is merely a system of logic consisting of premises and conclusions. Base 10 is only one of many possible number systems. Base 10 numbers are useful for many everyday things, but other systems might be equally useful.

The day of the final arrived. My anxiety was still high, but at least I thought I understood. You guessed it, only one question, "Invent a number system." Either I understood or it was too late. My future graduate studies depended on my ability to invent a number system. So I wrote, "Let there be an oar and a rubber boot." I proceeded to define a binary number system with two elements, an oar and a rubber boot. I was in the professor's office the next day to see if I was going to graduate school or not. He handed me my paper with a large red *A* written across the top. I thanked him, breathed a sigh of relief, and vowed to never take another math class as long as I lived.

My first year of graduate school was very difficult. Not only was there a tremendous amount of work, but there also seemed to be too many contradictions. The content of learning psychology challenged many of my fundamental beliefs. There were numerous contending systems, each claiming to explain learning. I struggled for days trying to explain learning of the concept *green* using only *S-R* (stimulus-response) bonds. I found myself in the basement of the psychology building feeding rats that were on a deprivation schedule. Why was I feeding rats when I wanted to know how to teach children? I was about ready to give up and look for a real job.

About this time, B. F. Skinner visited the campus. Like my fellow classmates, I went to hear the great man. I don't remember any details of his lecture, but his response in the question and answer period changed my life. A member of the audience said, "Dr. Skinner, in your book (which he named) you said such and such (some detail of Skinner's theory); but tonight you seemed to contradict yourself by saying such and such"—he quoted a part of Skinner's speech.

"Hell," said Skinner, "do you think I believe everything I ever wrote?"

This was a great insight for me. Here was a great author saying he changed his mind and now disagrees with his earlier self. However, what he said next changed my life.

"What I've tried to do," continued Skinner, "is to make only a few assumptions and then see how much of human learning we can explain with only these assumptions." He went on to defend his theory and the point he made in his speech. I stopped listening before he ended his explanation.

"Good grief," I thought, "psychology is just an oar and a rubber boot as well. Psychological systems are not reality either, but merely logical systems that try to explain what we observe in the real world. Behavior is merely one logical system that is tested against reality to see how good a match can be found. Just like there can be many different number systems, there can be many different psychological systems. Each is tested against reality to see how closely it fits, but none are reality, merely inventions."

I returned to my studies with renewed enthusiasm. I looked upon all theories as artificial systems and found them fascinating. I stopped trying to make all theories agree and force them to form one great truth. It became a game to see if I could identify the theorist's assumptions and conclusions. It was fascinating to observe that some systems were carefully constructed and logical, while other systems were very loosely constructed and often violated the canons of logic. I realized that theory building is our puny attempt to understand our world by inventing artificial systems and trying them out against the world.

Later in my graduate career I had one additional insight. We were studying learning and some instructional theories. It was apparent that learning theories tended to explain how persons acquire and store knowledge, but they have very little to say about how an instructor should structure and sequence knowledge to promote efficient and effective learning. It occurred to me one could build a logical system, a theory, about instruction. So I said, "Let there by an instructional oar and a rubber boot" (from the preface of Merrill, 1994).

In Pursuit of e^3 (Effective, Efficient, Engaging) Instruction

Early in my career I realized that instructional design consisted of two primary activities: what to teach and how to teach. The goal became to build a system of instructional design that followed Skinner’s strategy, i.e., make as few assumptions as possible, form some prescriptive statements about instructional design, and see if we can prescribe a wide variety of instructional strategies from these fundamental components.

Teaching Concepts

In 1968, I returned to Brigham Young University from a year as a visiting assistant professor at Stanford University. I was working on an instructional strategy for teaching concepts. My studies of formal concept learning in graduate school suggested that learning a concept involved presenting examples and non-examples (Bruner, Goodnow, & Austin, 1956). Most of these laboratory studies had used formal concepts–red circles, green triangles, and so forth. Very little had been done to investigate teaching concepts using real-world tasks.

I had begun to prepare a proposal for doing research on concept teaching. Bob Tennyson, who I had not previously met, walked into my office and announced, “I’ve come to work with you.” I indicated that I had no research funds and would be unable to pay him for his work. He offered to work merely for the experience. “Have you ever written a proposal?” I asked. He had not, but was sure that he could. I handed him my notes, the call for a proposal from NSF, and sent him away. Two days later he put a draft proposal on my desk. It was terrible, but it was a draft. After considerable discussion and several drafts, we submitted the proposal. It funded Bob's graduate education for the next three years.

Our first study (Tennyson, Wooley, & Merrill, 1972) found exceptional results. The best strategy for concept teaching consisted of presenting a definition, presenting matched examples and non-examples, presenting a divergent set of examples, and using an easy-to-hard sequence of examples. Our measure was correct classification of subsequent randomly sequenced examples and non-examples. We also measured classification errors of overgeneralization, under-generalization, and misconception. We compared four treatment groups. We hypothesized that the group that did not have matched examples and non-examples would over-generalize–they did; the group that did not have a divergent set of examples would under-generalize–they did; and the group that had examples that shared an irrelevant attribute would form a misconception–they did.

We subsequently conducted additional studies refining our strategies using different age subjects and different concepts (Merrill & Tennyson, 1977a). Our research continued to support our winning strategy. Tennyson spent the next several years continuing the investigation of concept teaching (Tennyson & Cocchiarella, 1986; Tennyson & Park, 1980). We described and illustrated our instructional strategy in a book that has since guided the effective, efficient, and engaging design of concept lessons for many designers (Merrill & Tennyson, 1977b; Merrill, Tennyson, & Posey, 1992). It is still a very effective instructional strategy.

The Task/Content Matrix

In 1972, it was a surprise and an honor to be invited to contribute a chapter, Instructional Development: Methodology and Research, for the first volume of AERA *Review of Research in Education* (Merrill & Boutwell, 1973). As we examined the literature, it became evident that different investigators often used the same words in reference to completely different strategies. In order to make prescriptive statements about objectives (what to teach) and instructional activities (how to teach), it was evident to us that there needed to be a descriptive language that allowed precise description of these two aspects of instructional design. A way to precisely describe what was taught and how it was taught was needed.

While in graduate school I had the opportunity to read *The Conditions of Learning* in manuscript before it was published (Gagne, 1965). My search for prescriptive guidelines for effective, efficient, and engaging instruction was rewarded. I immediately resonated with Gagne's categories of learning and his assumption that different kinds of learning required different kinds of strategy for effective presentation and assessment. Most of my previous explorations in learning theory attempted to explain all learning with a single set of principles. It was also difficult to translate these theories of learning into prescriptions for instruction.

As we attempted to apply Gagne's 1965 categories, we felt that they were incomplete. I had previously attempted to clarify his categories by proposing a two-dimensional scheme (Merrill, 1971) (see Table 1). On one dimension I put a unit, a chain, and multiple chains. On the other dimension I included emotional, psychomotor, memorization, and complex cognitive learning. Gagne's categories are in parentheses.

Table 1. Ten Categories of Learned Behavior

Emotional	Emotional (Signal Learning)		
Psychomotor	Topographic (Stimulus Response)	Chaining (Chaining)	Complex Skill (new)
Memorization	Naming (new)	Serial Memory (Verbal Association)	Discrete Memory (Multiple Discrimination)
Complex Cognitive	Classification (Concept Learning)	Analysis (Principle Learning)	Problem Solving (Problem Solving)

As we attempted to describe the content involved in the studies we were reviewing, we felt that there were some categories missing in the Gagne scheme. His multiple-discrimination accounted for remembering facts but did not obviously include categories for remembering the definition of a concept, remembering the steps in a procedure, or remembering the statement of a principle. It seemed more logical to us to separate the content to be learned from the performance of the student with regard to the content. We suggested three levels of performance: *remember* content, *use* content, and *find* new content. Following Gagne's lead, we suggested four kinds of content: *facts, concepts, procedures,* and *principles*. The result of our reflection on how to describe what to teach was a performance/content matrix for classifying instructional outcomes, at least in the cognitive domain (See Table 2).

FIND				
USE				
REMEMBER				
	FACT	**CONCEPT**	**PRINCIPLE**	**PRINCIPLE**

Table 2. The Performance-Content Matrix

Gagne's category of concept classification corresponded to our use-concept cell; his rule-using category corresponded to our use-procedure cell; and his higher order rule category corresponded to our use-principle cell. Gagne's problem solving or higher order rules did not seem sufficient for creative behavior with regard to concepts, procedures, and principles. The learned performance of defining a new concept (an activity essential to science), of inventing a new procedure (an activity common to engineering and especially computer programming), and discovering a new principle (the primary goal of science) did not appear to be adequately included in Gagne's scheme. We added a *find* performance category to accommodate these types of learning.

Elaboration Theory

Gagne's hierarchy analysis is a bottom up prerequisite analysis approach. In a lecture to my instructional design class, I proposed a whole-task approach in which the analysis started with the simplest version of a whole task and then with successive cycles of instruction gradually elaborated this task by adding complexity. Charlie Reigeluth was in the class and volunteered to write a version of my lecture for publication. This started our work on elaboration theory (Reigeluth, Merrill, Wilson, & Spiller, 1980). Reigeluth went on to investigate this approach in considerable detail (Reigeluth, 1983, 1999a). Elaboration theory started our thinking about whole tasks that led to the principle of task-centered instruction in our more recent work.

Primary Presentation Forms

My father was an artist–a landscape painter. As a small boy I wanted to be an artist like my father. I thought that if I could just have a large box[1] of Crayola Crayons, I would be able to paint beautiful landscapes like my father. For every birthday, I would request a large box of crayons. I was unaware of the precarious financial affairs of my parents. My dad never said they couldn't afford a large box of crayons. He merely sat down with four crayons – red, yellow, blue, and black – and a piece of paper and colored a beautiful landscape. By example, he taught me the primary colors and mixing pigments. For my birthday I would get a box of 8 Crayola Crayons. My dad would point out that I had four more crayons than I needed to paint beautiful landscapes. I didn't become an artist, but I never forgot my primary colors and how to combine them to get all the colors of the rainbow.

As I attempted to find a way to describe instructional strategies, it occurred to me that there must be some primary presentation forms from which all instructional strategies could be constructed and thus described. As I studied the instructional strategies in the literature we had collected, it occurred to us that there are two levels of content: a general level and a specific level. (Every composition teacher stresses this observation in their classes – but I didn't realize this until some years later.) I also observed that there were really only two things that an instructor could do with content: present it to the student or ask the student to remember or use the content. Combining these two dimensions led to the primary presentation form matrix. The content dimension had two values: *generality* (for the general case) and *instance* (for the specific case). On the instructional dimension we called presenting *expository* and application *inquisitory*. This led to four primary presentation forms (PPF): expository generality (EG), expository instance (Eeg), inquisitory generality (IG) and inquisitory instance (Ieg). We used the symbols in the parentheses as shorthand for describing instructional strategies. This allowed us to unambiguously describe almost any instructional strategy in terms of the primary presentation forms involved. For example, EG_1, EG_2, EG_3, etc. describes a lecture presenting a series of generalities without examples. The numbers indicate different generalities as contrasted with a repeat of the same generality. The strategy EG_1 Eeg_1, EG_2 Eeg_2, etc. describes a presentation of a series of generalities each followed by a corresponding example. A discovery strategy might be represented by Ieg_1, Ieg_2, Ieg_3, *IG* from which the learner is to discover the generality from a series of examples that he or she must figure out.

We also realized that there were *secondary presentation forms* (*SPF*)–teaching activities that enhanced learning but were not directly related to presenting or applying the content. Our attempts to unambiguously describe instructional strategies also caused us to recognize a number of relationships among the primary presentation forms that we called *interdisplay relationships (IDR).*

Component Display Theory (CDT)

During the 1970s, I was director of the Brigham Young University Division of Instructional Research, Development, and Evaluation. Our students during this period conducted scores of research studies exploring many aspects of the task/content matrix, primary presentation forms, secondary presentation forms, and interdisplay relationships. As a result of this work, I formalized our content classification scheme and strategy description into what came to be called Component Display Theory (CDT). The name deserves some explanation. We felt that each primary presentation form comprised a display to the student. These displays are the components of an instructional strategy, hence, component display theory.

CDT, as it came to be called, consists of three parts: (1) a scheme for describing the content to be taught–the task/content matrix; (2) a scheme for describing instructional strategies–primary presentation forms, secondary presentation forms, and interdisplay relationships; and (3) a set of rules that relate the two. CDT identifies which combination of PPF, SPF and IDR are most appropriate for teaching each cell in the task/content matrix.

Selecting Instructional Strategies and Media (Merrill & Goodman, 1972) presented an early version of CDT. *The Instructional Strategy Diagnostic Profile* (Merrill, Reigeluth, & Faust, 1979; Merrill, Richards, Schmidt, & Wood, 1977), later called *The Instructional Quality Inventory* (Ellis et al., 1978), also presented a manual to train people in developing effective instructional strategies based on our early work on CDT. The presentation of CDT in the Reigeluth Green Books (Merrill, 1983, 1987a, 1988) provided the wide spread dissemination of this work. The most complete presentation of CDT is found in Merrill (1994).

TICCIT

In 1966, I visited Vic Bunderson at the University of Texas. He had established a computer-based instruction laboratory that involved an IBM 1500 system, one of the early mainframe CBI systems. This was the beginning of our collaboration. We vowed at this time that we would one day work together in the same institution. In the early 1970s, I had arranged an appointment for Vic at Brigham Young University to work with our laboratory there. During the interview with the administration, he received a phone call from NSF indicating that he had received major funding to build a new CBI system. He turned down the appointment at BYU because he needed his lab at Texas to do the project.

Later we shared a room at a convention, and he indicated that the project was bigger than he anticipated. I offered to help. We visited NSF together, and I returned to BYU with a contract to work on the TICCIT[2] project.

The challenge of the project was to design an authoring system. We struggled with many ideas. Bunderson proposed a system that had a variety of different instructional approaches built into the system. The learner could then select the instructional approach they felt was best for them. Harvey Black, a colleague at Brigham Young University and a collaborator on the TICCIT project, felt that students would not have sufficient information to make a wise selection before the fact. He suggested that a learner could only make a decision about what they needed next when they were involved with the learning. We came up with the notion of a “momentary comprehension index,” that is, what the learner understands at a given moment in time.

About this time, NSF decided to consolidate the project at a single university and BYU was chosen for the site. Bunderson and many of his personnel from the Texas lab moved to Provo, Utah to continue the project. In the meantime, we were struggling with how to author for the system. I was working on Component Display Theory, and we had already identified primary presentation forms. Harvey Black suggested that only when given a rule (expository generality) could students determine if they needed an example. Only after having studied several examples could students determine if they were ready for practice. So we put the primary presentation forms as button commands on a special keyboard. Thus, given an objective for a segment of instruction, students could select *rule*, *example,* or *practice* by the touch of a button. We also added an *easy* and *hard* button, which allowed the student to get an easier or harder rule, example, or practice item. By means of these buttons, TICCIT was unique in that it allowed learner control, not just of content, but of the strategy to be used.

During a site visit from NSF, someone raised the concern that students may not know which button to select next. The *help* key told them what was available but did not give them any advice about which presentation form would be most helpful. I remembered a lecture on the future of teaching machines (circa 1963) by my major professor, Lawrence Stolurow (1961). In this lecture, he suggested that the teaching machines of the future would contain a teacher function that would interact with the student and a professor function that would monitor the teacher’s strategy, and when a given strategy did not seem to be working would provide advice as to what to try next. I remembered this lecture and answered this concern by suggesting that we would have an *advice* key that would access an advice function that would help the student decide which learner control key to select next.

After the meeting, our team strongly suggested that I had gotten carried away, that we had no idea how to build an advice system. After several members of our team had struggled with this problem, the task to design the system fell on my shoulders. Expert systems were not yet widely available, so I decided to build a decision tree that would provide the required advice to the student. To make this work, we determined an ideal strategy, “the all American strategy.” This strategy represented what we thought would be the best use of the learner control keys by a student. We then compared the student’s path through the learner control keys with our ideal strategy. The adviser then gave “local” advice; that is, it recommended the key that would be the best for the student to try at the time the advice was requested. It was a very sophisticated early version of an overlay expert system.

Our team developed a complete math zero (basic algebra) curriculum and an English writing program. The TICCIT system and curriculum were tested at Maricopa Community College in Phoenix and at BYU, and it continued to run at both locations until into the 1990s. At Maricopa Community College, TICCIT was used as main-line instruction. An evaluation of the system showed that English students scored higher on tests of writing skills and essay tests than did the comparison group in regular lecture classes. In the math classes students scored higher on their posttests than did the comparison groups in regular classes (Alderman, 1979). The English program has been transported to a more current programming language and is still available online (http://webclips.byu.edu). I suspect that this program holds the record for the longest running CBI program.

There was an attempt to create a commercial version of the TICCIT system. It was used for a time by the military. The advisor system was not included in the commercial version. To our knowledge, another system that allows learner control of strategy with an expert system advisor had not yet been built.

The TICCIT system pioneered a number of developments that are now common on all computer systems. Although multimedia was still in the future, the system was one of the first to have colored text and graphics (they were pretty primitive by today’s standards). The system used an early version of windows, also pretty limited by today’s standards. The system constructed displays for the student “on-the-fly” from resource files that were combined with text templates to create either presentation or practice displays from the same content files. The design of the TICCIT system is described in Merrill, Schneider, and Fletcher (1980).

Learner Control

As far as we were able to determine, no one had previously provided for learner control of instructional strategy. The TICCIT system allowed for both content control, selecting the next segment of instruction from a menu, and strategy control, provided by the *rule, example, practice, easy, hard,* and *advice* learner-control keys. We were anxious to learn more about the effectiveness of this version of learner control. With the TICCIT system, we had a very good laboratory instrument for conducting research. Our students conducted dozens of studies. The results showed: (Merrill, 1975, 1980, 1984)

(1) Students can decide how many examples and practice items they need for mastery;

(2) Allowing students to determine the sequence of rule, example, and practice forms does not improve performance over those who have a fixed rule, example, practice sequence;

(3) Students who have control over generality help performed more efficiently and effectively than other groups; and

(4) Students who have control over example and practice help perform less efficiently and less effectively than other groups.

Automating Instructional Design

During the 1980s, I found myself at the University of Southern California. I taught a seminar on authoring systems. We explored many of the very early authoring systems. One of the assignments of the class was to design an authoring system. As I read the student projects toward the end of the semester, one paper stood out above all the rest. The syntax revealed that it was obviously written by an international student, but the content was very insightful. I asked Zhongmin Li[3] to stop and see me after class. Thus began a very fruitful collaboration.

During this period of time, one of my consulting opportunities was to review some computer-based instruction developed by a major Air Force training company. The instruction was early CBT and involved a kluge of equipment including two monitors and an analog audio system. The instruction consisted of wall-to-wall text on one monitor and a very nice graphic on the other monitor. The audio read the text to the student. I suggested that this was not a very effective instructional strategy, and Mayer (2001) has since demonstrated the ineffectiveness of this instructional approach. The company agreed to let us try to build some instructional shells that would enable their "designers-by-assignment" to build more effective instruction for different kinds of learning outcomes. I approached Zhongmin about building such a shell for naming parts. He agreed. A week later he demonstrated for me not only a shell into which any content for naming the parts of something could be imported, but he also demonstrated an authoring system that could be used by designers-by-assignment for importing the content into the shell. Subsequently, we also designed and programmed shells for teaching concepts and teaching procedures (Li & Merrill, 1990).

In a contract with the Army Research Institute, we proposed to build an instructional design expert system. This system would ask a series of questions of the author and then prescribe the most effective instructional strategy to use (Merrill & Li, 1989). It then occurred to us to combine our authoring shells with the prescriptive system so that the system would not only recommend an appropriate strategy but would also select an appropriate authoring shell and prompt the user to import their content into this shell for delivery to their students.

ID Expert

At this time both Zhongmin and I moved to Utah State University and, with funding from various government sources and a major contract with IBM, founded the ID_2 Research Group. We were joined by Mark Jones and a number of graduate students and continued our work on designing an instructional design expert system. A group from Germany visited our campus and subsequently provided a very large contract to build ID Expert, a commercial version of our instructional design expert system (Li & Merrill, 1991; Merrill, 1987b; Merrill & Group, 1998; Merrill & Li, 1989, 1990). Version 1 of the system was completed when the company suffered serious financial problems and discontinued its business. We also lost another very large contract at this same time and the work on ID Expert was discontinued.

ID Expert was a very ambitious project. The goal was to reduce the labor involved in authoring computer-based instruction by an order of magnitude. The system consisted of several subsystems working together: 1) a set of reusable instructional strategy algorithms (transaction shells) for different kinds of instructional outcomes based on instructional principles (CDT); 2) a decoupled knowledge base that allowed the designer or system to attach a given knowledge object to any of the instructional strategy algorithms, thus allowing for reuse of knowledge objects within the system; and 3) a set of instructional parameters that allowed the instructional strategies to be modified by merely selecting a different parameter value (Merrill, Jones, & Li, 1992; Merrill, Li, & Jones, 1992a).

Initial authoring consisted of identifying the content to be taught and entering it into the knowledge base. The system contained default strategy parameter values that would then allow it to automatically format the instructional strategies for interaction with the student. A second level of authoring allowed the author to “open the hood” and adjust strategy parameter values to modify the instructional strategies. The system allowed for multiple strategies to be assigned to a given lesson or different strategies to be assigned to different students. The ultimate goal was to include a “professor” function that would monitor student performance and automatically adjust strategy parameters as necessary to accommodate the learning needs of a given student. This adaptive instruction feature was planned for phase 3 of the project but was never completed because of the demise of the funding company.

Instructional Transaction Theory

In order to develop our tools for automating instructional design, we found that it was necessary to develop more precise instructional design theory (Merrill, Li, & Jones, 1990a, 1990b, 1991). My contribution to the work was to try to extend CDT to a more precise level, so that we could describe content that could be manipulated in a computer system to automatically create instruction from only the content. It was also necessary to develop a more detailed description of instructional strategies on which our instructional design shells could be based.

The what-to-teach side of the equation was extended to describe knowledge objects (Jones, Li, & Merrill, 1990; Merrill, 1998, 2001b, 2001c, 2002b). We identified three components of knowledge: entities, activities, and processes. We also identified properties and defined each of these components in terms of properties. An *entity* is defined by a set of properties each of which has a set of legal values. Each legal value can be represented by a portrayal. Changing the portrayal changes the appearance of the entity. An *activity* is defined as some action on the part of the learner that triggers a process. When executed, a process results in some consequence that is defined as a change in the value of one or more properties of some entity. A *process* also has a set of conditions that are defined as values on a set of properties. A process only executes when the conditions equal the appropriate property values.

We also simplified the Performance/Content Matrix to identify five kinds of learning outcomes: *information-about, parts-of, kinds-of, how-to,* and *what-happens. Information-about* and *parts-of* correspond roughly to facts; *kinds-of* corresponds to concepts; *how-to* corresponds to procedures; and *what-happens* corresponds to principles in the former scheme. We also identified an information-level (generality) and a portrayal-level (instance) for each of the five categories of learned outcomes.

In this knowledge representation, a definition of a concept (kind-of) is a list of defining properties and the value each must assume for a portrayal to be a member of the class. A step in a procedure (how to) is an action performed by the student. A condition is a value on a property. A consequence is a change in the value of a property.

We also identified PEA-nets (process-entity-activity –nets) that define the dynamic relationship among these three components of a knowledge object. An activity (action by a learner) triggers a process. If the conditions are true (the condition properties have the appropriate values), then the process executes—meaning that it changes the values of the consequence properties.

The how-to-teach side of the equation was extended to more precisely identify the relationship between our knowledge objects and the demonstration and application of this knowledge (Li & Merrill, 1990; Merrill & ID2_Research_Team, 1993; Merrill, Jones, &

Li, 1992; Merrill, Li, & Jones, 1991, 1992a, 1992b). An instructional strategy is defined as a primary presentation form, which we simplified to TELL, ASK, SHOW, DO operating on a component of a knowledge object. Table 3 indicates the consistent strategies for kinds-of, how-to, and what-happens.

	INFORMATION		PORTRAYAL	
	PRESENT (TELL)	**RECALL (ASK)**	**DEMONSTRATE (SHOW)**	**APPLY (DO)**
Kinds-of	**Tell the definition.**	**Recall the definition.**	**Show several specific examples.**	**Classify new examples.**
How-to	**Tell the steps and their sequence.**	**Recall the steps and their sequence.**	**Show the procedure in several different situations.**	**Carry out the procedure in new situations.**
What-happens	**Tell the conditions and consequence involved in the process.**	**Recall the conditions and consequence involved in the process.**	**Show the process in several different situations.**	**Predict a consequence or find faulted conditions in new situations.**

Table 3 Consistent Information and Portrayal for Categories of Learning

Electronic Textbook

Mark Lacy and Leston Drake joined our ID_2 Research Group shortly before the demise of the ID Expert project. Using largely internal funds, we were able to continue our work to develop systems for automating instructional design. Mark was the primary developer of the *Electronic Textbook*, a very easy-to-use authoring shell with built-in instructional design for teaching naming, concepts, and procedures (Merrill & Thompson, 1999). This tool was available for a short time as a commercial product under the name *IDXelerator*. The Electronic Textbook consisted of three built-in instructional algorithms, each implementing the rules of Component Display Theory: an *information-about* (facts) lesson, *kinds-of* (concept) lesson, and a *how-to* (procedure) lesson. Authoring consists of putting the appropriate content into a knowledge base for each kind of lesson. The system then generated presentation and practice for the student appropriate for each type of lesson.

Instructional Simulator

Leston was the primary developer of the *Instructional Simulator*, a very easy-to-use simulation authoring and delivery system that combined instructional strategies with simulation (Merrill, 1999). This tool was available for a short time as a commercial product under the name *IDVisualizer*.

The Instructional Simulator implemented our work on knowledge objects. It is based on PEA-nets as described earlier in this article. Authoring the simulator consists of first defining a set of dynamic entities that may be parts of a larger system. For each entity a set of properties is identified along with the legal values that this property can assume. For each legal value a portrayal (usually a graphic representation) is developed and stored in a knowledge-base. Attached to each entity is a set of activities (actions defined by clicking on some part of the portrayal of the entity), one or more processes triggered by each activity, and the consequence of the process defined as a change in the value of one or more properties. The underlying system is an expert system that executes the PEA-net. Thus, the portrayals on the display can be manipulated by the student. See Figure 1 which illustrates the interface. Students interact by clicking on various parts of the pump to connect or disconnect them. The authoring system prompts the input of the activity-process-consequence rules in a very easy-to-use format. Once the portrayals for the different values of the properties of the entities have been developed, the actual simulation can be developed in a matter of a few minutes to a few hours depending on the complexity of the system. Authoring simulations in the Instructional Simulator was considerably more efficient than programming. The instructional simulator was our most sophisticated implementation of automated instructional design. Mark and Leston went on to form their own company, LetterPress Software. The ID_2 research group was unable to find additional funding to continue this work, and the company which bought the rights to this produce were unsuccessful in commercializing this work.

Figure 1 Interface for instructional simulator

First Principles of Instruction

When I developed CDT, I was not trying to develop an alternative method for designing instruction. The primary purpose was to develop a more precise terminology for describing instructional outcomes and instructional strategies. The second purpose was to identify relationships between the outcomes of instruction and the strategies thought appropriate to produce these outcomes. My intent was to identify underlying principles that were common to all models of instructional design. In spite of my intentions, CDT was often characterized as an alternative approach to instructional design rather than a more precise way to characterize existing approaches to instructional design.

When the second green book was published (Reigeluth, 1999b), Charlie indicated in the preface that there were many different instructional design theories and models, and that designers should learn many of these different approaches and use the approach that was most appropriate for a given situation. I thought that most of these different approaches were all based on the same underlying principles and that they differed mostly in implementation details. Charlie challenged me to demonstrate my assumption. I set out to determine the fundamental principles that were common to many of these different approaches.

The result of this effort was a set of principles that I called "First Principles of Instruction." These principles are summarized in Table 4. In the past few years I have tried to elaborate, clarify, and explain these principles and to demonstrate their presence in other instructional design theories and models (Merrill, 2001a, 2002a, 2006a, 2006b, 2007, In Press-a, In Press-b). I also proposed a content-first alternative to the classic ADDIE instructional design model called A Pebble-in-the-Pond approach to instructional development (Mendenhall et al., 2006; Merrill, 2002c, in press-c). Recent work has attempted to elaborate the content analysis required for task-centered instruction and to define an effective task-centered instructional strategy for teaching complex content (Mendenhall et al., 2006; Merrill, in preparation).

TRADOC (the army training and doctrine command) has recently adopted a new training methodology called GEL (Guided Experiential Learning). GEL is based on First Principles of Instruction. A task force of the audio visual department of the Church of Jesus Christ of Latter-Day Saints has recently adopted First Principles of Instruction as the instructional methodology for on-line training materials offered by the church. The author is humbled by these developments and anxiously awaits data from these two large organizations as to the effectiveness of their training based on these principles.

Table 4 First Principles of Instruction

Task-centered approach

- Learning is promoted when learners are engaged in a task-centered approach, which includes demonstration and application of component skills.
- A task-centered approach is enhanced when learners undertake a progression of whole tasks.

Activation principle

- Learning is promoted when learners activate relevant cognitive structures by being directed to recall, describe, or demonstrate relevant prior knowledge or experience.
- Activation is enhanced when learners recall or acquire a structure for organizing the new knowledge.

Demonstration principle

- Learning is promoted when learners observe a demonstration of the skills to be learned that is consistent with the type of content being taught.
- Demonstrations are enhanced when learners receive guidance that relates instances to generalities.
- Demonstrations are enhanced when learners observe media that is relevant to the content.

Application principle

- Learning is promoted when learners engage in application of their newly acquired knowledge or skill that is consistent with the type of content being taught.
- Application is effective only when learners receive intrinsic or corrective feedback.
- Application is enhanced when learners are coached and when this coaching is gradually withdrawn for each subsequent task.

Integration principle

- Learning is promoted when learners integrate their new knowledge into their everyday life by being directed to reflect on, discuss, or defend their new knowledge or skill.
- Integration is enhanced when learners create, invent, or extrapolate personal ways to use their new knowledge or skill in situations in their world.
- Integration is enhanced when learners publicly demonstrate their new knowledge or skill.

Summary

I hope that this nostalgic journey through a few highlights of my career has provided a bit of insight into how ideas develop and evolve. What have I learned about how to make instruction more effective, efficient, and engaging (e^3)? Considerably more than I knew at the beginning of my career. I do believe that we know a bit more about how to design instruction that works. I have been gratified by the many designers who have found our work helpful; however, far too much instruction is still not effective, not efficient, and not engaging. Do we have more to learn? I believe that we have just scratched the surface of how to design what to teach and how to teach.

What is my greatest concern? I'm concerned that there is not more effort being devoted to this question. The current zeitgeist seems to emphasize communities of learners, repositories of content, and electronic communication. There seems to be an assumption that information is sufficient and that e^3 direct instruction is no longer necessary. The Internet is swollen with information, and amidst this flood, there are only isolated islands of e^3 instruction. I am gratified by the adoption of our work by the army and the LDS church. Nevertheless, my hope is that our work may continue to provide a catalyst for further efforts to find ways to make instruction more effective, more efficient, and more engaging.

Notes

[1] I have often told this story indicating that I wanted a box of 64 crayons. However, I have recently learned that the box of 64 crayons was not introduced until 1958, so it must have been only 16 crayons. For sure it was more than 8.

[2] TICCIT is an acronym for Time-shared Interactive Computer-Controlled Instructional Television. The name was given by MITRE Corporation, who did the hardware development on the project. The original idea was to deliver instructional television into all the homes in Reston, Virginia. The nature of the project changed dramatically but the name was never changed to more accurately reflect the true nature of the system.

[3] Dr. Li eventually immigrated to the USA, changed his name to James Z. Li, founded LeadingWay Corporation and has built a very successful business in knowledge management.

References

Alderman, D. L. (1979). Evaluation of the TICCIT computer-assisted instructional system in the community college. *ACM SIGCUE Outlook, 13*(3), 5-17.

Bruner, J. S., Goodnow, J. J., & Austin, G. A. (1956). *A Study of Thinking*. New York: John Wiley & Sons.

Ellis, J. A., Wulfeck, W. H., Merrill, M. D., Richards, R. E., Schmidt, R. V., & Wood, N. D. (1978). *Interim Training Manual for the Instructional Quality Inventory SR*

78-5. San Diego: NPRDC.

Gagne, R. M. (1965). The Conditions of Learning. New York: Holt, Rinehart & Winston.

Jones, M. K., Li, Z., & Merrill, M. D. (1990). Domain knowledge representation for instructional analysis. *Educational Technology, 30*(10), 23-30.

Li, Z., & Merrill, M. D. (1990). Transaction shells: a new approach to courseware authoring. *Journal of Research on Computing in Education*, *23*(1), 72-86.

Li, Z., & Merrill, M. D. (1991). ID Expert 2.0: design theory and process. *Educational Technology Research and Development, 39*(2), 53-69.

Mayer, R. E. (2001). *Multimedia Learning*. Cambridge: Cambridge University Press.

Mendenhall, A., Buhanan, C. W., Suhaka, M., Mills, G., Gibson, G. V., & Merrill, M. D. (2006). A task-centered approach to entrepreneurship. *TechTrends, 50*(4), 84-89.

Merrill, M. D. (1971). Necessary psychological conditions for defining instructional outcomes. *Educational Technology, 11*(8), 34-39.

Merrill, M. D. (1975). Learner control: beyond aptitude-treatment interactions. *A V Communications Review*, *23*, 217-226.

Merrill, M. D. (1980). Learner control in computer-based learning. *Computers and Education*, *4*, 77-95.

Merrill, M. D. (1983). Chapter 9 --Component Display Theory. In C. M. Reigeluth (Ed.), *Instructional Design Theories and Models: An Overview of Their Current Status*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Merrill, M. D. (1984). Chapter 17 --What is learner control? In R. Bass & C. R. Dills (Eds.), *Instructional Development: The State of the Art II*. Dubuque: Kendall/Hunt Publishing.

Merrill, M. D. (1987a). Chapter 7 A lesson based on Component Display Theory. In C. M. Reigeluth (Ed.), *Instructional Design Theories in Action* (pp. 201-244). Hillsdale, NJ: Lawrence Erlbaum Associates.

Merrill, M. D. (1987b). An expert system for instructional design. *IEEE Expert*, *2*(2), 25-40.

Merrill, M. D. (1988). Chapter 3 Applying Component Display Theory to the design of courseware. In D. H. Jonassen (Ed.), *Instructional Designs for Microcomputer Courseware* (pp. 61-95). Hillsdale, NJ: Lawrence Erlbaum Associates.

Merrill, M. D. (1994). *Instructional Design Theory*. Englewood Cliffs, NJ: Educational Technology Publications.

Merrill, M. D., & ID_2_Research_Group. (1998). ID Expert: a second generation instructional development system. *Instructional Science, 26*, 243-262.

Merrill, M. D. (1998). Knowledge objects. *CBT Solutions*(March/April), 1-11.

Merrill, M. D. (1999). Instructional transaction theory (ITT): instructional design based on knowledge objects. In C. M. Reigeluth (Ed.), *Instructional Design Theory and Models: A New Paradigm of Instructional Theory Vol. II*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Merrill, M. D. (2001a). First principles of instruction. *Journal of Structural Learning and Intelligent Systems, 14*(4), 459-466.

Merrill, M. D. (2001b). A knowledge object and mental model approach to a physics lesson. *Educational Technology, 41*(1), 36-47.

Merrill, M. D. (2001c). Toward a theoretical tool for instructional design. *Instructional Science, 29*(4-5), 291-310.

Merrill, M. D. (2002a). First principles of instruction. *Educational Technology Research and Development, 50*(3), 43-59.

Merrill, M. D. (2002b). Knowledge objects and mental models. In D. A. Wiley (Ed.), *The Instructional Use of Learning Objects* (pp. 261-280). Washington DC: Agency for Instructional Technology & Association for Educational Communications and Technology.

Merrill, M. D. (2002c). A pebble-in-the-pond model for instructional design. *Performance Improvement, 41*(7), 39-44.

Merrill, M. D. (2006a). Hypothesized performance on complex tasks as a function of scaled instructional strategies. In J. Elen & R. E. Clark (Eds.), *Handling Complexity in Learning Environments: Theory and Research* (pp. 265-281). Amsterdam: Elsevier.

Merrill, M. D. (2006b). Levels of instructional strategy. *Educational Technology, 46*(4), 5-10.

Merrill, M. D. (2007). First principles of instruction: a synthesis. In R. A. Reiser & J. V. Dempsey (Eds.), *Trends and Issues in Instructional Design and Technology* (2 ed., pp. 62-71). Upper Saddle River, NJ: Merrill Prentice Hall.

Merrill, M. D. (In Press-a). Converting e sub3 learning to e 3rd power learning: An alternative instructional design method for e-learning. In S. Carliner & P. Shank (Eds.), *E-Learning: Lessons Learned, Challenges Ahead (Voices from Academe and Industry)*: Pfeiffer/Jossey-Bass.

Merrill, M. D. (In Press-b). First Principles of Instruction. In C. M. Reigeluth & A. Carr-Chellman (Eds.), *Instructional Design Theories and Models III*. Mahwah: Lawrence Erlbaum Associates Inc.

Merrill, M. D. (in press-c). A task-centered instructional strategy. *Journal of Research on Technology in Education*.

Merrill, M. D., & Boutwell, R. C. (1973). Instructional development: methodology and research. In F. Kerlinger (Ed.), *Review of Research in Education Vol. 1*. Ithaca, NY: Peacock Publishers.

Merrill, M. D., & Goodman, I. R. (1972). *Selecting Instructional Strategies and Media: A Place to Begin*. Syracuse, NY: National Special Media Institutes.

Merrill, M. D., & ID2 Research Group. (1998). ID Expert: a second generation instructional development system. *Instructional Science*, 26,243-262.

Merrill, M. D., & ID2_Research_Team. (1993). Instructional transaction theory: knowledge relationships among processes, entities and activities. *Educational Technology, 33*(4), 5-16.

Merrill, M. D., Jones, M. K., & Li, Z. (1992). Instructional transaction theory: classes of transactions. *Educational Technology, 32*(6), 12-26.

Merrill, M. D., & Li, Z. (1989). An instructional design expert system. *Journal of Computer-based Instruction, 16*(3), 95-101.

Merrill, M. D., & Li, Z. (1990). An instructional design expert system. In S. Dijkstra, B. H. A. M. Van Hout Wolters & P. C. V. Sijde (Eds.), *Research in Instruction: Design & Effects*. Englewood Cliffs, NJ: Educational Technology Publications.

Merrill, M. D., Li, Z., & Jones, M. K. (1990a). Limitations of first generation instructional design (ID1). *Educational Technology, 30*(1), 7-11.

Merrill, M. D., Li, Z., & Jones, M. K. (1990b). Second generation instructional design (ID2). *Educational Technology, 30*(2), 7-14.

Merrill, M. D., Li, Z., & Jones, M. K. (1991). Instructional transaction theory: an introduction. *Educational Technology, 31*(6), 7-12.

Merrill, M. D., Li, Z., & Jones, M. K. (1992a). Instructional transaction shells: responsibilities, methods, and parameters. *Educational Technology, 32*(6), 12-26.

Merrill, M. D., Li, Z., & Jones, M. K. (1992b). Instructional transaction theory: an introduction. In S. Dijkstra, et al (Ed.), *Instructional Models in Computer-based Learning Environments*. New York: Singer Verlag.

Merrill, M. D., Reigeluth, C. M., & Faust, G. W. (1979). The instructional quality profile: a curriculum evaluation and design tool. In H. O'Neil (Ed.), *Procedures for Instructional Systems Development*. New York: Academic Press.

Merrill, M. D., Richards, R. E., Schmidt, R. V., & Wood, N. D. (1977). *The Instructional Strategy Diagnostic Profile Training Manual*. Orem, Utah: Courseware Inc.

Merrill, M. D., Schneider, E. W., & Fletcher, K. A. (1980). *TICCIT*. Englewood Cliffs, NJ: Educational Technology Publications.

Merrill, M. D., & Tennyson, R. D. (1977a). Concept classification and classification errors as a function of relationship between examples and non examples. *Improving Human Performance*.

Merrill, M. D., & Tennyson, R. D. (1977b). *Teaching Concepts: An Instructional Design Guide*. Englewood Cliffs, NJ: Educational Technology Publications.

Merrill, M. D., Tennyson, R. D., & Posey, L. O. (1992). *Teaching Concepts: An Instructional Design Guide* (Second ed.). Englewood Cliffs, NJ: Educational Technology Publications.

Merrill, M. D., & Thompson, B. (1999). IDXelerator: learning-centered instructional design. In J. v. d. Akker, R. M. Branch, K. Gustafson, N. Nieveen & T. Plomp (Eds.), *Design Methodology and Development Research in Education and Training* (pp. 265-277). Dordrecht / Boston / London: Kluwer Academic Publishers.

Reigeluth, C. M. (1983). The Elaboration Theory of Instruction. In C. M. Reigeluth (Ed.), *Instructional Design Theories and Models: An Overview of their Current Status* (pp. 335-381). Hillsdale, New Jersey: Lawrence Erlbaum Associates, Inc.

Reigeluth, C. M. (1999a). The elaboration theory: guidance for scope and sequence decisions. In C. M. Reigeluth (Ed.), *Instructional Design Theories and Models: A New Paradigm of Instructional Theory Volume II* (pp. 425-453). Hillsdale, New Jersey: Lawrence Erlbaum Associates, Inc.

Reigeluth, C. M. (Ed.). (1999b). *Instructional-Design Theories and Models: A New Paradigm of Instructional Theory* (Vol. II). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Reigeluth, C. M., Merrill, M. D., Wilson, B., & Spiller, R. T. (1980). The elaboration theory of instruction: a model for structuring instruction. *Instructional Science, 3,* 30-31.

Stolurow, L. M. (1961). *Teaching by Machine*. Washington DC:: US Department of Health, Education, and Welfare.

Tennyson, R. D., & Cocchiarella, M. J. (1986). An Empirically Based Instructional Design Theory for Teaching Concepts. *Review of Educational Research, 56*(1), 40-71.

Tennyson, R. D., & Park, O.-C. (1980). The Teaching of Concepts: A Review of Instructional Design Research Literature. *Review of Educational Research, 50*(1), 55-70.

Tennyson, R. D., Wooley, R. R., & Merrill, M. D. (1972). Exemplar and non exemplar variables which produce correct classification errors. *Journal of Educational Psychology, 63*, 144-152.

M. David Merrill makes his home in St. George, Utah. He is an instructional effectiveness consultant, a visiting professor at Florida State University, a visiting professor at Brigham Young University – Hawaii, and professor emeritus at Utah State University. Since receiving his PhD from the University of Illinois in 1964 he has served on the faculty of George Peabody College, Brigham Young University - Provo, Stanford University, the University of Southern California and Utah State University. He is internationally recognized as a major contributor to the field of instructional technology, has published many books and articles in the field and has lectured internationally. Among his principle contributions: TICCIT Authoring System 1970's, Component Display Theory and Elaboration Theory 1980's, Instructional Transaction Theory, automated instructional design and ID based on Knowledge Objects 1990's, and currently

First Principles of Instruction. He was honored to receive the AECT Life Time Achievement Award. He and his wife Kate together have 9 children and 37 + 2 (by marriage) grandchildren which he claims as his most important accomplishment.

Web sites:

http://cito.byuh.edu/merrill

www.mdavidmerrill.com

email:

mdavid.merrill@gmail.com

mailing address:

1812 West Sunset Blvd 1-145

St. George, UT 84770

M. David Merrill

Professor Emeritus Utah State University

Visiting professor Florida State University

Visiting professor Brigham Young University Hawaii