The Development of Authentic Educational Technologies[1][1]

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The goal of this article is to briefly describe how an authentic technology develops and to give two examples of current social and educational technologies. Our deeper purpose is to encourage a dialogue between educational technologists about the conceptual structure of our research and practice. We agree with Greg Kearsley (1998) that our field needs a new conceptual basis and that our new understanding "must be one that does not assume a logical/rational world...." (p. 51). We believe that our problems are opportunities for a developmental step forward. In other places we have described our concerns about a number of distressing features of this field's current dilemma in previous articles (Clark 1983, 1988a; 1988b; 1994a; 1994b; Clark and Estes, 1998) and only summarize them briefly here.

The main source of concern for most observers of our field is a persistent irrelevance in our inquiry and practice. In the past we have attributed the cause of the problem, in part, to a history of mindless and demonstrably wrong advocacy of popular electronic media to foster motivation and learning. It is also very troubling that most university-based educational technology programs have continued to abdicate their responsibility to confront these problems (Clark, 1978, 1989). The recent glut of students, rushing to Internet-based, multimedia, distance education has not served to discipline our academic programs.

In this series of articles, we discuss the conceptual difficulties that we believe have led to what we now view as a crisis in our field. In our previous article (Clark and Estes, 1998) we described the consequences of our almost exclusive conceptual patronage of indefensible, craft-based points of view. In that article, we suggested that we do not have, and never have had, an educational "technology". While there are notable exceptions, our analysis of the field suggests that when we succeed, it is often because we generate limited, contextualized, non-transferable craft solutions to educational problems. We share the concerns voiced by other critics of our field

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[1] This article is the second of a multi-part discussion of technology in education. In part one (Clark & Estes, 1998) we argued that what we now call educational technology is, in fact, limited, often inadequate and non-generalizable craft. We called for the development of authentic technology based firmly on scientific work. In this article, we define authentic technology and describe how it can be developed and tested. We propose collaboration between practitioners, technologists, scientists, craftspeople and artists to develop authentic educational technologies. We are aware that some of our ideas are controversial and so invite your comments and questions. They should be addressed to Richard Clark (clark@usc.edu) or Fred Estes (Fred_Estes@hp.com). In our next installment, we will summarize and reply to the comments you make to the ideas in the two articles.

who suggest that we are not committed to understanding or using the science that illuminates the problems we confront. Instead, educational technologists tend to “scientize” craft by citing research studies that are often poorly designed and largely irrelevant (Clark, 1989) to support interventions that seldom generalize beyond their initial application. We asked for a dialogue concerning the benefits of committing ourselves to authentic science-based educational technology.

John Dewey was making a similar complaint about the craft basis of all of education nearly a century ago (Dewey, 1900). The situation has improved somewhat since then but nearly the same set of concerns has been recently voiced by the National Academy of Sciences and by the National Research Council in this decade (Druckman & Bjork, 1991; 1994). The ninety-year span between these two discussions underscores the duration, difficulty and extent of the challenge. Yet in this article we want to turn away from emphasizing the negative. We agree with colleagues such as Stellan Ohlsson (1996) who notice that pointing out errors and assigning blame may be necessary for error correction in learning about anything. We hope that a dialogue based on rational discourse, replicable evidence, error correction by accepting responsibility for mistakes and providing positive examples and a willingness to serve as our own, most severe critic, will move us forward.

What is an “authentic technology?

Our technology scorecard is not entirely negative. It is possible to be thrilled by some of the recent, very effective developments in social and educational research and practice based on authentic technologies. We define an “authentic educational technology” as educational solutions resulting from a systematic analysis that identifies the problem being solved, selects and translates appropriate, well-designed research and applies it to design culturally appropriate educational solutions.

We expect that craft solutions will always be necessary and will always make a significant contribution to solving educational problems. We urge collaboration between research-trained technologists and educational craftspeople of the kind that made Sesame Street an extraordinary success in the 1970's. The development of Sesame Street required the close collaboration of child development and instructional psychology researchers on the one hand, and a variety of art and television craft specialties, on the other. Its worldwide success in raising reading and math scores for children, and its adoption in over 80 nations of the world, indicate the potential power of authentic technology. Our problem now is not to encourage craft; it is to develop research-trained technologists who can collaborate productively with creative educational craftspeople. We believe that this kind of collaboration has resulted in effective authentic technology traditions in medicine and engineering.

While positive examples of authentic performance and educational technologies are rare, and often developed outside of educational technology, they can serve as both evidence of, and as models for, future developments. In this article, we want to draw on two examples of authentic educational technology and use them to illustrate an approach and a direction for the future. We will choose one example from recent developments in drug abuse prevention and treatment and another from instructional design. Our discussion will attempt to answer four questions: 1) What problem is being solved by an authentic technology? 2) What body of research and theory addresses the problem most effectively? 3) How do we translate research into effective technologies? (What is the science to technology “spiral”?) and 4) How do we determine that a technology has “solved” an educational problem? (What is the generalizability of technology and how is it demonstrated to be better than a craft solution?).

What problem is being solved by authentic technology? We must begin our search for the development of authentic and effective educational technologies by being clear about the problem we are solving with a new technology. One of the most damaging traditions in educational technology is our temptation to advocate educational solutions apart from a clear analysis of the specific problem needing to be solved. For example, Rossett and Czech (1996) find that many professionals with graduate level training in instructional design and performance technology admit to doing little or no problem analysis. Solutions must be specifically targeted to a type of problem or we run the risk of providing an elegant and expensive solution for the wrong problem. It appears that educational technologists often advocate media to solve learning problems when the strongest evidence supports the conclusion that media do not influence learning (Clark, 1983; 1994a). Electronic media are more likely to solve problems in instructional delivery such as those associated with access, cost and learning time. Educational and performance technologists tend to skip this essential and initial step in technology development. When we advocate a solution without a clearly limited description of its application boundaries and limitations, we do ourselves and our clients a disservice. When we are not clear about the problem being solved it is impossible to connect with the research that will help us find a solution.

Many critics of educational technology have made these points. Roger Kaufman (1998), for example, has been eloquent in pointing out that “...we are getting things backward. Again, instead of focusing on the results and payoffs for whatever we deliver, we are slipping back into old responses that have made many earlier good ideas fail for the wrong reasons... the ultimate panacea... is now the Internet... *(Many educational technologists)*... seem committed to the view that this is ‘the answer to end all answers’... Constructivists..and others who have a ‘solution’ in search of a problem... find... satisfactions unrestricted by objectives or purposes” (*italics added*, p. 63). The “what is the problem being solved” issue is especially vexing since it was educational technology that successfully championed the specification of learning and instructional objectives in the 1960's and 1970's as a way to introduce alternative instructional design and delivery media to schools.

So, what problems should be solved? How do we analyze problems prior to solving them? While we are not aware of any comprehensive “problem domain” analyses, it seems reasonable to assume that problem definitions must be drawn from the existing body of experimental research and theory. For example, problems that involve the motivation of students to learn seem to us to connect with a very different body of experiments and theory than problems concerning student access to instruction and information. Motivational and access problems tend to be addressed by research and theory that is quite different than learning or performance problems. Within each of these more-or-less separate research areas, one finds many sub-varieties of specific problems.

For example, research on motivation seems to focus on two different types of motivational problems, commitment and mental effort. Commitment is defined as persistence at a task over time in the face of distractions. Mental effort is defined as the number of non-automatic elaborations used to learn or solve novel tasks and problems. See, for example, the discussion of motivational “indexes” in chapter 1 of Pintrich & Schunk (1996). The reader can imagine other research and theory driven taxonomies of problems. For example, a powerful way to understand learning problems is to draw on cognitive learning theories and break problems into “declarative” and “procedural or propositional” issues (e.g. Anderson, 1993; van Merrënboer, 1998). The learning of declarative knowledge can then be broken down further into different types of declarative knowledge such as processes, concepts and principles, and so on. A similar analysis could be performed on educational "access" issues. This is the area that may eventually prove most fruitful for multi-media, Internet, Intranet and distance educational technology specialists concerned with "delivery" efficiencies.

We turn next to two current examples of authentic technologies, one focused on drug abuse prevention and treatment and another focused on learning and performance. Each of these authentic technologies began with a very clear analysis and understanding of the problem being solved. In fact, both of these examples are successful, in part, because of their developers refused to consider specific solutions until the problem being solved was more clearly understood. In the first example, Prochaska et al.'s (1994) technology for substance abuse treatment, a re-analysis of the problem being solved was a key element in finding a new solution to a very old problem.

Examples of Problem-Focused Authentic Technologies: Prochaska's Six-Stage Change Program

Many readers may not be aware that the health care systems of many of the largest nations in the world have recently changed their approach to the treatment of substance abuse. Most nations have now adopted the exciting new "six-stage change technology" developed by James Prochaska, a professor of psychology who specializes in drug abuse prevention, and his colleagues. Prochaska's father died from the complications of alcohol abuse when he was a teenager. Thus, perhaps more than his colleagues, Prochaska was distressed that the evaluations of our most powerful substance abuse treatment approaches indicated that they were only effective in about two to three percent of cases. After many years of research on the topic, he came reluctantly to the point where he felt the need to "start again".

He vividly describes (Prochaska et al., 1994) the exact moment, during a summer vacation in Cape Cod, when his insight about the problem being solved by the over 400 therapies attempting to prevent drug abuse, led him to a new technology. As he searched for a better way, he was impressed with recent work in psychology that attempted to categorize the many different psychotherapeutic approaches by the problems that each solved best.

Essentially, Prochaska realized that most of the therapies used in drug abuse treatment were not focused directly on modifying substance abuse. Most of these therapies were solving many different types of problems. Existential therapy, for example, was focused on identifying life goals and solving "meaning of life" problems, not on changing habitual and destructive drug addiction behaviors. Psychoanalytic therapies emphasize the analysis of resistance and emotional arousal. Nether of these therapies directly addressed the problem of getting addicted people to change their self-destructive behavior or to maintain a change. His insight, simple to describe but very complex in origin, was to re-analyze the problems being solved. He reasoned that there must be "clusters" of theories and approaches that focus on different "stages" in the complex series of events that precede the decision to actively avoid harmfully addictive substances.

Prochaska identified six stages or problems to be solved by treatment technologies (and developed a six-stage technology for change). Those stages are: 1) Pre-contemplation (Do I have a problem?); 2) Contemplation (Do I want to do anything about my problem?); 3) Preparation (I want to do something, so what options are open to me?); 4) Action (I'm now changing my habits. Will this treatment plan help me withdraw from addictive substances effectively?); 5) Maintenance (What will help me stay away from addictive substances and the contexts which lead me to abuse?), and 6) Termination (I did it!). Thus, in our view, Prochaska's contribution to a new worldwide technology for treating one of the most destructive problems confronting society was to reconceptualize the problem being solved.

Compare Prochaska's approach to the myriad of self-help programs available in bookstores and on the Internet. While some of them are worthless nonsense, many of these programs are developed by practitioners who have been successful in helping others quit smoking, lose weight, assert themselves, manage their time or any of a number of positive changes to improve their lives. These successful programs are most often based on their personal experience in working with clients and on insight, serendipity, and trial and error. This is characteristic of craft knowledge (Clark & Estes, 1998) and often craft-based knowledge is the best and most useful knowledge we have in a particular area, at any given point in time. The problem that concerns us our failure to move beyond craft-based knowledge and build a science-based technology where we do have the necessary scientific knowledge.

The problem with craft-based solutions is that 1) we don't know why they work or when they will work, 2) it is difficult to transfer these programs to other people, other problems, or other social settings, and 3) they are unconnected to our knowledge of the way the world works, our science, because we have not determined the cause and effect principles involved. The infomercials feature a new program every month because these successful programs usually turn out to be highly situated in a particular context and only applicable to certain types of people, under certain conditions. To make it more confusing, the conditions of applicability are unknown.

Does this mean that we should spurn craft- based knowledge and demean the practitioners who create and use these programs? Not at all. To paraphrase Teddy Roosevelt, we should do all we can, with what best we know now, wherever we are now, with whatever tools we have now. To do less would be to fail in our responsibility to do the best we can to solve real problems in real time and to forgo the opportunity to improve the lives of others. However, to remain content with craft approaches is to fail to in our responsibility to create better solutions. To go beyond craft requires the collaboration of practitioners, technologists, scientists, craftspeople and artists.

Examples of Problem-Focused Authentic Technologies: E. Gagne and J. van Merrënboer

In the past, most of our instructional design systems were varieties of the Instructional Systems Design (ISD). While space prevents a discussion of the problems in this model, suffice it to say that it was very strong on process and very weak on instructional method. Many ISD models exist and most attempt to provide process sequences and procedures for producing instructional materials. The effectiveness of instruction produced using the ISD model varied greatly depending on who was implementing the model. This is a finding that tends to indicate a craft product. In general, the problem being solved by the ISD model was not learning, but instead ISD models solved process problems for the identification, design and development of training. Most ISD models ignored current research on learning or instruction.

Recently, two individuals have succeeded in translating the cognitive research on learning into highly effective instructional design technologies. Ellen Gagne, Robert Gagne's daughter and a professor at Catholic University, has described a very effective approach to designing instruction for K-12 classrooms based on the huge body of cognitive learning research generated by John R. Anderson (1993) and others. Jeroen van Merrënboer, a Dutch educational technologist and professor at the University of Twente, has translated a similar body of research into a design model to facilitate the learning of complex technical knowledge for adults.

Both of these authors divide their time between research and technology development. Both have invested the effort required to master the large body of research that supports the design systems they developed. Both have clearly begun with an analysis of the learning problems their systems are designed to solve. Both systems would now profit from collaborations with craft experts. The books and articles that describe both design systems begin with a clear description and analysis of the declarative and procedural knowledge supported by the design models. Both systems draw on the construct and operational definitions used in cognitive learning research when defining the types of knowledge and instructional methods in their design systems. Each can serve as a model for the development of future, problem-focused instructional and training design systems as cognitive learning theory evolves. Both show great promise as solutions to complex learning problems. Both technologies selected the best body of research on the learning of complex knowledge as the basis for the solutions that are suggested.

What body of research and theory should be used to develop authentic technologies?

We suggest three criteria for choosing research to be translated and applied in an authentic technology. First, we need to choose the most comprehensive, experimentally verified theory that predicts the outcomes (problems to be solved) of interest to the new technology. Second, the independent variables and interventions described in the theory must be morally, ethically and practically acceptable in the target application environments. Third, the theory and related experimental studies that provide evidence for the theory, must permit a description of the "active ingredient" that causes or alleviates the problems being solved in a way that permits "no plausible alternative explanation".

Selecting Appropriate Research. In the first place, technologists must look for comprehensive theories. In choosing theory, we must go beyond the limited and narrowly focused theories that are often available. For example, if our problem involves adults, research with children may often be relevant. If the problem exists in a school setting, research conducted in the military or business may be relevant. Thus we must conduct the widest search possible for the most inclusive and robust theories. We must also avoid the temptation to choose a theory because it fits our bias or reflects our current experiences or beliefs. We must be willing to change our minds if well-designed experiments fail to confirm our prejudices or our experience.

For example, Ford (1992) counts over thirty-two, research-based theories of motivation to learn. He notes that many of these theories overlap. Pintrich and Schunk (1996) describe four different theories of motivational learning goal orientation developed by researchers who have given different construct names to almost exactly the same constructs. Because of this duplication and lack of communication among researchers, we need to be very cautious in picking among large body of theories. In fact, since only one or two motivation theories attempt to incorporate the others (e.g. Ford, 1992) the choice in the motivational area is made easier.

The problem is made more difficult as the number and diversity of comprehensive theories increases. This is certainly the case when one considers research on learning and instruction. The field is ripe with many small and large theoretical efforts (see for example a discussion by Clark (1988a). Yet most researchers who have recently attempted to produce design technologies have settled on the comprehensive body of research produced by John R. Anderson (1993). Other bodies of research-based theory might eventually produce authentic technologies that have different strengths because they focus on different learning problems.

This complexity suggests that the many types of expertise required to produce authentic educational technologies development will require team efforts. Highly collaborative teams composed of researchers, designers, and representatives of the target audience will most likely be more successful than individuals who try to represent very different and diverse experience. Prochaska, and van Merrënboer discuss their own collaborations with colleagues possessing different but complementary knowledge. Prochaska made the decision to accept all major theories but focus the technology based on those theories on the type of problem that reflected one of the six stages in the cycle of change in addictive behavior. This way he and his colleagues did not have to discard many powerful theories, they merely used them appropriately. The design technology of van Merrënboer is focused on the most effective theories on the learning of complex knowledge.

Moral, Ethical and Cultural Issues. On the second issue, our search for practical, moral, cultural and ethical acceptability requires a personal knowledge of the application context for a technology. One of us had a personal epiphany on this issue in India when we made a remark to an Indian colleague about India's "population problem". We were politely but firmly told that "India does not have a population problem, it has a food supply problem". At that point, we learned at the deepest level that the way a problem is defined in the application setting for a technology determines, in large part, the receptiveness of people in the setting for the solution being developed.

In our initial analysis, we must ask whether the problems and solutions addressed by a specific technology will be acceptable to our clients. Robert Heinich (1984) have addressed similar acceptability problems in the educational technology literature. Prochaska wisely did not discard theories that were philosophically acceptable to their advocates and prospective clients. He selected the set of theories that could be used practically to solve at least one of the problems addressed at one or more of the six stages in the cycle of change for addictive behaviors. He tried to find many small theories that were aimed at each change stage. He and his colleagues reasoned that at least one or more of the cluster of theories at each stage would be acceptable to clients who were going to use the resulting technology.

While Prochaska solved his acceptability problem by choosing many theories but assigning them to an appropriate stage in the change process, van Merrënboer is not allowed a similar luxury. He has selected a specific set of theories to translate and now runs the risk of alienating educational technologists who support different theories. We need a constant dialogue about the adequacy and limitations of alternative theories of learning and instruction.

Yet, one of our biggest concerns in this area is that many educational technologists have philosophical and belief barriers to accepting any technology based on experimental science and quantitative research. Many of these barriers get expressed as "post modernist" views of science. We suggest that those concerned about the potential of science to inform educational technology practice read the eloquent defense of this point of view by Nathan Myhrovold (1998) in a recent issue of Science. Myhrovold serves as the chief technology officer for Microsoft Corporation. It is our impression that much (but not all) of the resistance to using science to develop new educational technologies is based on stereotypes and a lack of understanding about research and scientific method.

Identifying Active Ingredients for Authentic Technologies. Finally, authentic technology design requires an operational definition of the generic "active ingredient" in the independent variables and interventions that have been used in successful experiments that verified the theory being adopted. A quick example can be found among shopper strategies for purchasing the least expensive in the "over the counter" remedies available in drug stores. The active ingredient in aspirin is 5 mg of an acid compound. This ingredient is available in equal amounts, and with equal impact no matter what medium carries it (e.g. gum, tablet, or liquid suspension) or what "brand" it sells under. Thus all aspirin products that contain the required 5mg. of active ingredient have a more or less equal biological impact, but not the same price.

Clark (1983,1994a) argued that the two active ingredients influencing learning from electronic media delivered instruction are the "instructional methods" and the "task knowledge" embedded in instructional frames. A method was defined as any external representation of a cognitive process necessary for the learning and application of task knowledge of students who could not, or would not, provide the cognitive process for themselves. Task knowledge is defined as the various types of declarative and procedural knowledge necessary to perform the task but unavailable to learners before instruction. The ID technology of van Merrënboer (1998) presents many other important active ingredients.

Identifying active ingredients in research and theory is one of the most creative acts required for technology development. It is a skill that is not well understood or taught and it is seldom modeled adequately. We have been impressed with the discussions about this issue by Reigeluth (1983), Gage (1985) and Landa (1983). Clark (1983; 1988a) described an approach to this problem for delivery and instructional technologies. Clark (In Press 1998) describes examples of the approach for motivation technologies. Essentially we must be able to identify the generic causal agents that influence the problems we are solving at the deepest, most structural level in order to develop the most effective technology.

For example, a popular craft-based solution to motivational problems in work settings is to provide “employee empowerment”. This involves allowing employees to form work teams that make decisions about how they will perform a job. In some settings these empowered teams have been very successful, in other settings they have failed miserably and expensively. An “active ingredient” analysis of the empowerment intervention suggests that when it succeeds, it does so because those applying it feel that they will gain significant control and become more successful. In some cultures and work settings, being permitted to make decisions about one’s job is considered to be a speedy way to fail at the job and therefore is rejected. So the active ingredient in these studies could be called “control beliefs” and defined as any job condition that the individual or team perceives as resulting in increased control or success.

This active ingredient analysis is most obvious to researchers who understand the modern “expectancy-control” theories of motivation (Clark, In press 1998). Without active ingredient analysis, empowerment interventions run the risk of expensive failure at work, in navigation rules for Internet and computer-based distance education and in the classroom. Thus, ingredient analysis is also the basis for the generalizability advantage of an authentic technology over a craft. The more we are aware of the active and necessary ingredients that form the basis of the interventions suggested by technologies, the greater the chance that the technology will transfer to new settings, people and varieties of tasks. Identifying active ingredients in instructional treatments is the extraordinary strength of both the Ellen Gagne and van Merrënboer design technologies. Both of these technologists are very clear about the key elements of their interventions.

<u>How do we translate research into effective technologies?</u>

Those who have attempted to apply research findings have learned quickly, and sometimes painfully, that such transfers are not direct or easy. Learning about positive correlations between age and height, on the one hand, and learning and time on the other hand, should not lead us to expect that we will necessarily grow taller and smarter if we only wait for time to pass. Yet this kind of twisted logic can be found in many existing instructional media technologies. Because we find learning correlated with the use of new electronic technologies, we wrongly assume that providing more technology will produce learning advantages. We need a way to conceptualize the process by which theories are developed, and active ingredients are identified and translated into technology. Our suggestion is to focus on the four stages in a “science to technology spiral”.

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SCIENCE - TECHNOLOGY SPIRAL MODEL

We suggest a four-stage model for describing the process by which science develops and is, in turn, translated into social or behavioral technology. We briefly describe the model and then apply it to understanding the translations that occur in the two authentic technologies we are using as examples. The four stages that characterize the movement from science to technology we will call: 1.) Descriptive research; 2.) Experimental verification of theory; 3) Generic Technology (T1); and 4) Contextualized Technology (T2). The first two stages are commonly associated with science. The final two stages define technology development.

Stage 1: Descriptive Scientific Research Stage (S1). In stage 1, descriptive research attempts to produce reliable measurement and description of variables and processes of interest. At this stage, very creative new ideas are explored. Nothing is rejected if it can be measured. Construct definition, measurement and hypothesis generation are the key descriptive goals. Both qualitative and quantitative methods attempt to tease out new variables and processes of interest to scientific research. In fact, it is possible that many descriptive research problems result from analyses of craft solutions. Since all craft solutions that are successful in any setting contain elements that might have been sufficient to solve the problem once, many successful technologies have resulted from descriptive reasoning about why the craft solution worked.

Yet no technology results directly and immediately from stage one inquiry. Hypotheses developed here need to be tested at the next stage before they are useful. The survey methods, naturalistic observations, thinking experiments, literature searches for construct validation, path analysis and Liseral or Structured Equation models used at this stage all serve to define key variables and provide evidence for relationships between variables. This leads to important hypotheses that need to be tested and linked into theories at the next stage. Conclusions about the factors that cause a problem cannot be drawn and no interventions or authentic technologies can be developed based on descriptive data.

Most educational technologists do not conduct descriptive research. Most do not even review the research that has been conducted at this stage unless there is a question about the definition or psychometric properties of constructs that are being considered for inclusion in a technology. The research conducted at this state is often very creative and naturalistic. For example, in the 1850's, the Viennese physician Semmelweis noticed that four times as many women died of symptoms called “childbirth fever” in a birth clinic staffed by physicians than in a similar clinic staffed by midwives. He could not describe the cause of the deaths until a physician friend cut himself with a knife he had used for dissecting cadavers and died of symptoms identical to childbirth fever. Semmelweis connected these two events and reasoned that since physicians who delivered babies in their clinic had often been dissecting cadavers just before the delivery, he suggests that “cadaverous matter” may have been causing the deaths through transmission by the physicians. He planned an experiment to validate his descriptive observation. He asked physicians to wash their hands before attending childbirth. Subsequent deaths in the physician’s clinic fell to the level of the midwife’s clinic. His experiment was an example of science at stage 2.

Stage 2: Scientific Experiments and Theory Development (S2). In stage 2, theory development and the experimental verification of theories is carried out through the testing of hypotheses suggested at the descriptive level. Theories are built, checked in experiments and revised. Theoretical paradigms compete for attention. Quantitative and qualitative methodologies cooperate to test the key hypotheses in theories. Those theories that encompass the greatest range of phenomenon and survive experimental tests, continue. Confounding and artifact are eliminated from the typical experimental designs that test competing theories. The unconfirmed or narrow theories should fail but sometimes survive out of the ignorance or ego problems of researchers and journal editors. Rival hypotheses and alternative explanations for the effects measured in controlled studies are explored and, if possible, eliminated. Active ingredients that produce measured results are identified. Paradigms shift and change with shifts in evidence and fashion. Advanced theories that survive this stage are ripe for the development of authentic technologies.

Semmelweis's hand washing experiment is a good example of the long history of connections between science and technology. While there was no effective knowledge of micro organisms in the 1850's, Semmelweis's instructions that doctors wash their hands before attending women in childbirth" decreased deaths. He assumed that the active ingredient causing death was "cadaverous matter" and that hand washing would eliminate the problem.

Stage 3: Generic Technology Development (T1). In stage 3, generic technologies are developed based on the strongest and most successful theoretical paradigms that have survived scrutiny at stage 2. This is the state where a generic active ingredient analysis is critical. Technologies must first be developed in a generic or decontextualized state so as not to confuse the issues surrounding the many unique limiting features of the setting or context in which they are being applied. For example, we need first to know that a need to feel in control is the active ingredient that drives motivational commitment to learning goals. Only with then can we introduce the many conflicting types of control issues one finds in different application settings. (The issue of setting-specific translations of the active ingredients is introduced in the next stage). The goal at this stage is to generate a model that explains how to solve the problems that served as dependent variables in prior research.

Reigeluth (1983) notices that the reasoning at this stage is "backwards". Whereas research starts by trying to find a treatment that will "predict" changes in a dependent variable. Technology at the generic stage starts with the dependent or "problem" variable and attempts to incorporate the active ingredient into a generic treatment or intervention that will solve the undesired problem.

Prochaska's change strategy exists only at the generic T1 stage. He and his colleagues wisely decided to design a generic technology that could be "translated" by psychologists in many treatment or prevention settings. This permitted the addition of local features that increased the cultural acceptability of the treatments without diluting the active ingredient. This is one of the strengths (and some have complained, one of the weaknesses) of his system. Its strength is that the generic, "active ingredient" description of the key elements of the successful interventions at every stage allows all users to translate the T1 ingredients in a way that will make them acceptable to their clients. Yet the clarity of the description of the T1 solutions permits users to make reliable and accurate applications in a great variety of culturally different settings.

Van Merrënboer used a similar strategy for his instructional design technology. He has a generic T1 system that cannot succeed without being procedurally translated for application in any specific application. He notes that his system "does not ... focus on ready made procedures to support the process of instructional design" (van Merrënboer, 1998, p. 1). He explains that it is to be "applied in conjunction with an ISD-model in order to receive support for the activities not treated in the model such as needs assessment, needs analysis, production of instructional materials, implementation, delivery and summative evaluation" (p. 3). Presumably, other T1 authentic technologies could be developed to accommodate the additional "activities".

Stage 4: Specific Technology Development (T2). In stage 4, generic (T2) technologies are translated for specific settings, people and tasks. An educational technology that is acceptable and effective in a North American K-12 classroom may not be acceptable in a Chilean K-12 classroom. An educational technology developed for San Jose, California may not be acceptable in San Pedro, California. The children's television series "Sesame Street" was eventually adopted for use in over 80 nations. In many of those settings, there were controversies about the almost total focus of the program on "cognitive skills" and an absence of "social skills" training. In other countries, the scripts had to be edited and new versions of the program were produced to change elements such as gender roles, situations, relationships and songs to make them culturally acceptable.

At this final stage, the generic T1 technology is shaped and translated for the unique cultural beliefs, expectations, knowledge and value patterns found in a specific application setting. The specificity of T2 technologies vary, depending on the novelty of the cultural expectations and values held by users who will experience the technology. It is also critical to note that only T1 technologies should be transferred between different settings. Since T2 technologies are specific to a context, one would not expect the intact transfer of T2 interventions to a different context to succeed.

Translating generic T1 technologies into specific T2 applications requires a great deal of experience with the culture and expectations found in the target setting. We are not aware of any science that informs this process and so we need to rely on existing craft, systems approaches and on a "trial and revise" correction cycle. Imagine a need to transfer a T1 technology for teaching concepts to a specific setting. It is easy to see how the knowledge and learning strategies people need to learn and perform can be described in a generic way. A concept is defined the same regardless of the context in which it is taught or learned.

Yet critical elements of instructional presentations such as our specific choice of the examples, simulations, and analogies used to illustrate concepts can and should change depending on local constraints. Important among those constraints are teachers and learner's beliefs. For example, the usefulness of certain types or format's for examples; the value placed on humor or a rejection of humor as "frivolous"; whether instructional decisions are typically made by learners or system managers; and the efficacy beliefs of learners and system managers, name only a few of many constraining beliefs. Much more work remains to be done at the T2 level to insure adequate translation of generic technologies.

Roles and Responsibilities. A few words about the various roles in this spiraling cycle of science to technology may clarify the dimensions of the type of collaboration we are calling for. First, while no one can juggle all the roles simultaneously, many people play more than one role. For example, practitioners who are responsible for implementing and delivering solutions to clients may function as a technologists at the T2 level while adapting a T1 technology for use in their specific organizations and clients, then shift to a craft role in improvising a part of the solution set where our scientific knowledge is missing or incomplete. So people may move among various roles as their needs, interests, and opportunities allow.

Second, it is clear that all the roles are necessary for optimal solutions of real world problems. Scientists add to our knowledge of the world, but it is not their job to apply that knowledge. Technologists use knowledge as the raw material to forge solutions at both the T1 and T2 levels. Practitioners deliver these solutions in the real world and employ craft to fill in the gaps of our knowledge. Craftspeople are those ingenious people who devise ways to make things work, even if they do not know why it works. For example, before there was a technology of anesthesia, a craft approach to pain relief was to give a patient as much whiskey as they could consume. At that time, whiskey was a responsible and compassionate (if dangerous) intervention.

Today, however, when we have a technology of anesthesia based on scientific knowledge, the use of whiskey is not an acceptable practice. We deplore the persistence of craft approaches when the state of our knowledge permits the development of authentic technology.

How do we determine that a technology has “solved” an educational problem?

Since substantive, multi-dimensional evaluation is seldom performed on educational interventions, the case for authentic technologies is more difficult. If we require adequate evaluation of interventions, the clear superiority of authentic technology over craft will be evident. Too many practitioners experience research as a complex, error filed process where competing claims are voiced constantly. Whereas information about craft solutions are most often based on “personal or organizational experience testimony” where the positive is emphasized and failures are not mentioned. To paraphrase an old saying in the media area, “The invisible virtues of craft are compared with the very visible mistakes made as we develop research-based authentic technologies”.

We are attracted to a combination of formative evaluation (in progress check’s accompanied by a revise cycle) and the adoption of a more elaborate version of the Kirkpatrick (1994) four level evaluation model used in business settings for summative evaluation. Kirkpatrick’s model permits us to distinguish among 1) motivation (like it?), 2) learning (learn it?), 3) application (use it?), and 4) results (payoff?). This is a check on the needs analysis and problem analysis that began the design cycle in the first place).

Formative evaluation can be performed at all of the four stages in the development of a technology. Outcome evaluation can most persuasively be performed only on T2 technologies but because of the indeterminate nature of the T1 to T2 translations, considerable uncertainty always remains about what has caused any measured gain (or lack of gain) at any of the four Kirkpatrick evaluation levels. It is discouraging that so little evaluation is performed on any educational innovation. This pattern makes it difficult to compare the effectiveness of authentic technologies with craft solutions. When evaluation is performed, it is often badly designed and focused mainly on reactions (which can be inversely related to learning, behavior and results) and secondarily on learning (and most learning evaluation is focused on memory for facts). We seldom evaluate transfer or results, and yet our goals are almost always to achieve transfer and to solve the problem that began the development process in the first place.

The Partnership Needed to Develop Authentic Technologies

One of the important implications of the Spiral Model of Science and Technology is the need for the collaboration of practitioners, technologists, and scientists. We feel that much of the controversy in this area results from two mistaken beliefs. One is that a good professional should do it all from basic, descriptive research to implementing the polished T2 solution set. The second is that some roles in this cycle are inherently more worthy of respect than others.

The first belief is a common, yet impossible problem. No one person can perform all the roles in the cycle simultaneously. First, the demands and opportunities of the organizations we work in put us all in different situations. Universities afford time for research and reflection; school classrooms and business settings demand swift, effective action, and consultancies provide an overview of the same problem in many settings and the bridge between theory and practice. Second, we all have different strengths and skills as a result of our aptitudes, interests, and focused experiences. The special skills and instincts we develop that make us so good in one role may be counterproductive in another role. A dispassionate, deeply analytical, and reflective approach will serve the researcher very well, but will be fatal to the classroom teacher and business trainer who need to respond fluidly and immediately.

The second misconception is related and deeply troubling. Unless we understand the roles of our collaborators in different phases of the cycle and can develop true respect for their contributions and the constraints they work under, we will not be able to collaborate effectively. Practitioners are not less worthy or less valuable than researchers; they are not simply people who could not make it in research. Researchers are not impractical nerds doomed by their timid souls to spend their cloistered lives proving the obvious at great expense to the taxpayers. Each role has a unique contribution to make and a need to partner with all the other roles to add to our knowledge and to solve real problems.

Summary and Conclusions

We are proposing collaboration between educational researchers and craftspeople on the development of authentic technologies. We believe that only with a commitment to authentic technologies can we hope to solve persistent problems with the utility and relevance of our educational technology interventions. We argue in this article, and an earlier discussion (Clark and Estes, September-October, 1998) that most of our current work can be described as limited and non-generalizable craft. We define an "authentic educational technology" as educational solutions resulting from a systematic analysis that identifies the problem being solved, selects and translates appropriate, well-designed research and applies it to design culturally appropriate educational solutions. We presume that educational technologists will want to take advantage of the extraordinary advances over the past two decades in the social and behavioral sciences in order to solve pressing educational problems.

In order to do so, we provide some preliminary answers to four troubling questions: 1) What problem is being solved by an authentic technology? 2) What body of research and theory addresses the problem most effectively? 3) How do we translate research into effective technologies? and, 4) How do we determine that a technology has "solved" an educational problem? As we attempt to answer those questions, we suggest that authentic technology design requires first a clear analysis and validation of the problem being solved and a determination to avoid our present error of "advocating solutions and looking for problems they will solve". A preliminary taxonomy of educational problem types was proposed centering on access to educational resources; the economics of educational treatments and outcomes; learning and performance issues; and motivation to learn and perform.

Next we recommended a strategy for identifying robust research that, when analyzed, will yield a generic model of the solution to an educational problem. We asked for three assurances when selecting research. First, that we choose the most comprehensive, experimentally verified theory that predicts the outcomes (problems to be solved) of interest to the new technology. Second, the independent variables and interventions described in the theory must be morally, ethically and practically acceptable in the target application environments. Third, the theory and related experimental studies that provide evidence for the theory, must permit a description of the "active ingredient" that causes or alleviates the problems being solved in a way that permits "no plausible alternative explanation". We clearly understand that each of these issues permits alternative views and respectful dialogue about alternatives between colleagues who may choose to disagree.

We then described a "science to technology" cycle. This cycle helps our understanding of the events that occur as basic science becomes applied science, and applied science is transformed into effective technologies. We proposed a four-stage cycle: 1) descriptive science where hypotheses are identified; 2) experimental research where theories are validated; 3) a generic technology (T1) stage where the analysis of research and theory permits us to identify the “active ingredient” in the research interventions or treatments that influenced the types of problems we want to solve; and 4) a contextualized (T2) stage where the active ingredient of the solution is translated for specific settings, cultures, and people. Our focus was on the two technology stages.

In T1, for example, we advised technologists to seek a generic “ active ingredient”. An example of an active ingredient is the active compound in aspirin. No matter how many brands or types of aspirin one encounters, we can be certain that the key component is the active ingredient. We gave many examples of the active ingredients in T1 educational technologies.

The second or T2 stage of technology development, knowing the chemical makeup of this acid compound is equivalent to describing a T1 generic technology. Yet in order to “take” or “administer” aspirin, we must combine the active compound into a variety of buffer and delivery media. Aspirin can be combined with a number of inert compounds and fluid suspensions and delivered orally or through injection, suppositories or skin patch. Oral delivery can take the form of swallowed tablets or liquid suspensions, sublingual tablets or liquid or a chewed gum. We acknowledge that both T1 and T2 technologies require collaborative work between people and teams with differing expertise. Our models for collaborations between craftspeople, artists and scientists include successful authentic technologies such as “Sesame Street”, the Prochaska Six-Stage Model for Change for the treatment of drug abuse (Prochaska et al., 1994), the instructional system designed by E. Gagne (Gagne, et al., 1993), and van Merrënboer’s Complex Cognitive Skills Training model (van Merrënboer, 1998). Finally, we propose adopting a version of the Kirkpatrick (1994) four level evaluation design for use in both formative and summative evaluation so that we can check the results of all authentic technologies and compare then with craft solutions.

We are deeply aware that space considerations required us to give only cursory descriptions of ideas and approaches that are very complex and, in a few cases, controversial. Our purpose in this article is to shift the direction of our dialogue a bit. We invite questions, suggestions and alternative views. We only hope that we can be constantly clear about the criteria we will use to determine which ideas will prevail. Our criteria emphasize measured gains that reflect a solution to the problem targeted by our technology. We know that this discussion is not finished. In our next installment, we will describe some of the replies and ideas that have been proposed about these ideas.

References

Anderson, J. R. (1993). Rules of the mind. Hillsdale NJ: Lawrence Erlbaum Publishers.

Clark, R. E. (1978). Doctoral research training in Educational Technology. *Educational Communication and Technology Journal.26*(2), 165-173

Clark, R. E. (1983). Reconsidering the research on learning from media. *Review of Educational Research. 53*(4), 445-459.

Clark, R. E. (1988a). The Future of Technology in Educational Psychology, In Wittrock, M.C. and F. Farley, (Eds.), *The Future of Educational Psychology,* Hillsdale, N.J.: Lawrence Erlbaum Publishers.

Clark, R. E. (1988b). When teaching kills learning: Research on Mathemathantics. In H.

Mandl, E. DeCorte, N. Bennett, and H. F. Friedrich (Eds.) *Learning and instruction: European research in an international context. Vol. 2.2*. Oxford, England: Pergamon. 1-22.

Clark, R. E. (1989). The future of technology in educational psychology. In M. Wittrock and F. Farley, The Future of Educational Psychology. Hillsdale NJ: Lawrence Erlbaum Publishers.

Clark, R. E. (1994a). Media will never influence learning. *Educational Technology Research and Development, 42*(3), 21-29.

Clark, R. E. (1994b). How the cognitive sciences are changing our profession. In Stolovitch, H. & Keeps, E. (Eds.), *Handbook of Human Performance Technology*. New York: Macmillan.

Clark, R. E. (October 1998). Motivating performance. Performance Improvement, 37(8), 39-47.

Clark, R. E. (In press). The CANE model of motivation to learn and to work: A two-stage theory process of goal commitment and effort. In J. Lowyck (Ed.) Trends in corporate training. Leuven Belgium: University of Leuven Press.

Clark, R. E. and Estes, F. (1998). Technology or craft: What are we doing? Educational Technology. 5-11.

Dewey, J. (1900). Psychology and educational practice. The Psychological Review, 7, 105-124.

Druckman, D and Bjork, R. A. (1991). In the Mind's Eye: Enhancing Human Performance, Washington DC: National Academy Press.

Druckman, D and Bjork, R. A. (1994). Learning, Remembering and Believing, Washington DC: National Academy Press.

Ford, M. (1992). Motivating Humans. Newberry Park California: Sage.

Gage, N. (1985). Hard *gains in the soft sciences: The case of pedagogy*. Phi Delta Kappa, Center on Evaluation, Development and Research, Bloomington, Indiana.

Gagne, E., Yekovich, C., and Yekovich, F. (1993). The cognitive psychology of school learning, Second Edition. New York: Harper Collins College Publishers.

Heinich, R. (1984). The proper study of instructional technology, Educational Communications and Technology Journal, 32(2), 67-87.

Kaufman, R. (January-February, 1998) The Internet as the Ultimate Technology and Panacea. Educational Technology. 38(1). 63-64.

Kearsley, G. (March-April, 1998). Educational Technology: A Critique. Educational Technology. 38 (2), 57-61.

Kirkpatrick, D. L. (1994). Evaluating Training Programs: The Four Levels. San Francisco: Berrett-Kohler Publishers.

Landa, L. N. (1983). The algo-heuristic theory of instruction. In C. Reigeluth (Ed.) Instructional design theories and models, Hillsdale, NJ: Lawrence Erlbaum Publishers.

Myhrovold, N. (1998, October 23). Supporting Science. Science (282), 621-622.

Ohlsson, S. (1996). Learning from error and the design of task environments. International Journal of Educational Research, 25(5), 419-448.

Pintrich, P. R. and Schunk, D. H. (1996). Motivation in Education: Theory, Research and Application. Englewood Cliffs, NJ: Prentice Hall.

Prochaska, J. O., Norcross, J. C., and Diclemente, C.C. (1994). Changing for Good. New York: Avon Books

Reigeluth, C. M. (1983). Instructional design, what is it and why is it? In C. Reigeluth (Ed.) Instructional design theories and models, Hillsdale, NJ: Lawrence Erlbaum Publishers

Rossett, A. and Czech, C. (1996). They really wanna but ... The aftermath of professional preparation in performance technology. Performance Improvement Quarterly, 8(4), 114-132.

van Merrënboer, J. J. G. (1998) J. Training complex cognitive skills, Englewood Cliffs, NJ: Educational Technology Publications.