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New Directions for Educational Technology

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Abstract: I see three important areas of research for the future development of educational technology: instructional strategy prescriptions, tools to help designers, and applications (contexts). The purpose of this chapter is to identify specific new directions, within each of these three areas, that I think are most important for future research. However, before discussing these new directions for educational technology, I would like to briefly comment on some concerns I have regarding many of the chapters in this volume.

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1. Concerns

My primary concern is that many chapters represent a very narrow view of the field. Most of them are about intelligent tutoring systems (ITS). Although this is indeed an important new direction for educational technology, it is only one of many important new directions. As Merrill [9] has pointed out, tutoring (whether done by an experienced human or an artificially intelligent machine) is not always the best mode of instruction. Computer-based simulations provide a powerful environment with which the learner can interact to discover principles and develop methods for solving problems in a much more powerful way than a tutor could ever provide through dialogue alone. And for automatizing lower-order skills (procedural knowledge) and facts (declarative knowledge), drill-and-practice games are far more cost-effective and motivational than an ITS. We must not ignore such other aspects of educational technology when we discuss important new directions deserving of our time and funders' support.

The foundations of educational technology are based in media, and focused on the "hard technologies" to the exclusion of the "soft technology" of how to optimize the process of learning. We have gone through cycles of embracing a hard technology as affording a radically improved method of educating children, then having our expectations shattered, then embracing a new hard technology, and so on. We have seen radio come and go, followed by tape-slide and television, to name the most famous cases. Part of the problem comes from overhyping and overpromising, part is due to failure to recognize that the hard technology is not a universal tool that is equally effective for all types of learning, and part is due to failure to recognize the importance of the soft technology -- instructional theory -- for guidance as to what the instruction should be like regardless of the medium (the hard technology). As McCalla warns in his chapter in this volume, ITS is in danger of falling into this same trap.

Another concern is that many reports and presentations on ITS remind me of "show and tell." There seems to be little interest in developing and reporting generalizable prescriptions or rules which govern an intelligent tutor. What little generalizing is done is usually along the lines of descriptive theory (e.g., cognitive learning theory) rather than prescriptive theory (instructional theory). Although there are indeed few rules or prescriptions which would generalize to all learning situations, surely the vast majority generalize beyond a single topic. In this volume Collins discusses the need for a design science similar to aeronautics. ITS projects should contribute toward the building of such a prescriptive design science or theory.

The other side of this coin is the syndrome of "reinventing the wheel" to which McCalla also referred in his chapter. Most ITS projects seem to have ignored the existing knowledge base of instructional theory when designing their intelligent tutors. Instructional theory offers many validated prescriptions (rules) which should govern any effective instructional system, including an intelligent tutor. In his chapter, Ferguson discusses the distinction between instruction and construction, and suggests that the ITS people may ignore the existing instructional theory knowledge base because they perceive it as irrelevant to their focus on construction. I certainly agree that the construction mind-set is important for the more complex kinds of learning, and I have used it recently in my work to develop prescriptions for teaching "understanding" [11].

However, in adopting such a mind-set, we must be careful to maintain our interest in prescribing what a teacher or other instructional medium should do to facilitate construction. In other words, instruction is also required for construction -- they are not mutually exclusive terms. It is not sufficient to just describe what goes on (or should go on) inside a learner's head; it is important to prescribe what a teacher (or other medium) should do to make it happen. And much of what exists in the current instructional theory knowledge base is indeed relevant to facilitating construction of meaning by a learner. I have seen some features of ITS's touted as a great discovery, when they were in fact a clear implementation of an instructional theory prescription. Reiser, in his chapter, discusses a variety of general prescriptions for an intelligent

programming tutor called GIL, including the timing of feedback and the use of examples. On the other hand, I have seen some ITS's which ignore some important principles of instruction. The quality of their tutoring would have been considerably improved if the developers had done some homework on instructional theory, or if an instructional theorist had been on the development team.

Another concern relates to the heavy reliance on observation of "experts" to derive rules to govern an ITS. More than half of my graduate students at Syracuse University were exteachers who were undergoing a career change. They typically had taught for as many as 10 to 15 years and were often among the best teachers. Universally, towards the end of my introductory course on instructional theory, several would comment, "If only I had known this when I was teaching, I would have been able to do so much better a job of teaching." To some extent, one could liken analysis of teachers' techniques now to the analysis of doctors' techniques a century ago. One could conclude, "Bloodletting is a common practice, so it must be good." There is a danger in analyzing current practice to prescribe what should be. It is but one of several approaches that should be used to build a sound prescriptive knowledge base (design science).

Another concern is the lack of emphasis on empirical comparisons to find out how good one's ITS really is. This is the flip side of the "show and tell" problem. Most projects have merely attempted to create a working ITS without concern for how well it compares with the most viable alternative approaches for teaching the same material. But, at the same time, much of the empirical research that is conducted by educational technologists is focused improperly on testing the validity of our methods. Whereas validity is the most important concern for descriptive theory, optimality is the most important concern for prescriptive theory. It is not a matter of whether a certain ITS can teach; rather, can it teach better than the best of the known alternatives. And even more importantly for a new technology, how can we improve it? The experimental study is terribly inadequate at providing empirical information to answer this question. But what are the alternatives? One possibility is a "formative evaluation" type of research which creates a piece of instruction solely on the basis of a prescriptive theory, then conducts one-on-one evaluations of the instruction to identify weaknesses and suggestions for improvement, which in turn reflect weaknesses and improvements for the theory itself [12]. Naturally, a representative sample of students is needed to assure reliability of findings. This form of research should yield a far greater wealth of information for improving a theory than an experimental study would, but much more work is needed to refine this research methodology.

A final concern is the lack of attention to system planning. Systems theory has been an important dimension of educational technology for several decades now. It is well understood that not only the effectiveness, but also the likelihood of adoption, of a new technology depends greatly on how it is to be used within the larger system of instruction. Again, an ITS project would be well advised to include an instructional theorist on its team.

In sum, I feel that ITS is indeed an important new direction for educational technology, but I have some serious concerns about some of the mind-sets which seem to be taking hold. First, there is the "narrow view" problem. ITS is but one important dimension of educational technology, and it is clearly not the best way to go for some educational needs. Furthermore, the hard technology and programming technology frequently receive too much attention relative to the soft technology of pedagogy or instructional theory. Second, there is the "show and tell" problem. There has been relatively little attempt to formulate generalizable prescriptions or rules (prescriptive theory). Third, there is the "reinventing the wheel" problem. All too often the existing knowledge base in educational technology (particularly instructional theory) has been ignored. Fourth, there is the "bloodletting" problem. Observation of experts should not be the only way we build our knowledge base. Fifth, there is the "lack of data" problem. To what extent is an ITS better than the best alternatives? Our research needs to focus more on optimality than validity to address this question. And finally, there is the "systems" problem. The design of an educational tool needs to be done with consideration for how it will be used within an educational system, rather than just developing it as a stand-alone entity.

Addressing these concerns is certainly one important "new direction" for educational technology. But what particular areas of research are most likely to advance our ability to improve education? As was mentioned at the beginning of this chapter, I see three important areas of research for the future development of educational technology: instructional strategy prescriptions, tools to help designers, and applications (contexts). Of these three, the area of strategy prescriptions is likely to be the most important, because it provides knowledge about how to effectively utilize the capabilities of the powerful new delivery systems to enhance learning.

2. Strategy Prescriptions

There are several important kinds of strategy prescriptions which are greatly in need of further development during the next decade: (1) prescriptions for types of learning which have been largely ignored by the field, such as understanding and generic skills; (2) prescriptions which take advantage of the unique capabilities of new technologies, such as simulations and intelligent tutoring systems; (3) prescriptions for structuring and sequencing a course or curriculum; (4) prescriptions for selecting mediational systems; (5) prescriptions for designing instructional-management systems; and (6) prescriptions for motivating learners.

2.1 Types of Learning

In our efforts to synthesize the current state of the art in instructional theory into a coherent, unified, prescriptive knowledge base, we have come to believe that there are in the cognitive domain four major types of learning which require very different methods of instruction [12]. In teaching these ideas to beginning graduate students, I have found that the most intuitive labels are: (1) memorizing information, (2) understanding relationships, (3) applying skills, and (4) applying generic skills. Memorizing information corresponds to Bloom's "knowledge," Merrill's "remember verbatim," and Ausubel's "rote learning," and is one aspect of Gagné's "verbal information." Understanding relationships is similar to Bloom's "comprehension," Merrill's "remember paraphrased," and Ausubel's "meaningful verbal learning," and is the other aspect of Gagné's "verbal information." Applying skills is the same as Bloom's "application," Merrill's "use-a-generality," and Gagné's "intellectual skills." And applying generic skills includes Bloom's "analysis," "synthesis," and "evaluation," Merrill's "find-a-generality," and Gagné's "cognitive strategies."

The various types of domain-specific content, such as concepts, procedures, and principles, can be acquired as any one of the first three types of learning: a concept can be memorized (either its definition or an example of it), or it can be understood (its relationships with other knowledge the learner has), or it can be applied (instances can be classified as examples or non examples of it). The fourth kind of learning is domain independent and generally requires more time to acquire. In our analyses of theories of instruction and learning, we have found that these four types of learning require greater differences in the instruction than any other categorization or factor.

The field of instruction (variously referred to as instructional psychology, instructional technology, instructional development, and instructional theory) has grown out of a behavioristic orientation which has focussed most efforts on prescriptions for memorizing information (association tasks) and applying skills (especially concept classification and procedure using). We have relatively very little in the way of validated prescriptions for facilitating the acquisition of understanding (meaningful learning). What work has been done has largely been on the development of descriptive learning theory, rather than prescriptive instructional theory. Considering recent advances in cognitive learning theory, it should be much easier now to develop useful instructional strategies for facilitating understanding. In fact, at Indiana University we have made progress recently on a project to develop prescriptions in this area [11].

Instructional theorists are already beginning to devote greater attention to generic skills: thinking skills, problem-solving skills, learning strategies, and metacognition. While much attention will continue to go to deciding what to teach in this area, it seems likely that instructional theorists will also place greater attention on figuring out how best to teach them. Of particular importance are prescriptions for designing a good simple-to-complex curriculum sequence for teaching a generic skill, and prescriptions for integrating such single-skill sequences with each other and with a range of domain-specific course sequences. We recently completed a project with Macmillan Publishing Company that worked on the development of both the sequencing and integrating prescriptions for a K-6 science program using the elaboration theory. This project resulted in some important new prescriptions for using the "simplifying assumptions" method to sequence generic skills and to integrate those sequences with the domain-specific sequences (biological, physical, and earth sciences) [13].

I hope and expect that we will see during the next decade much more work on these two areas of the cognitive domain (understanding and generic skills). But these areas are not the only types of learning which have been largely ignored by instructional theorists. Another type of learning is affective learning: attitudes and values, morals and ethics, social development, emotional development, personal development, and such. Martin and Briggs [8] have provided an excellent beginning for instructional prescriptions in this area. While much attention is also likely to be placed on deciding which ones to teach, there is a great need for advances on how to teach them. I hope the next decade will see considerable progress in this area, also.

However, the selection of instructional strategies should not just depend on the nature of the content. The nature of the learner is important, as well as the capabilities of the media that are available. In our work, we have found that the nature of the learner has a greater influence on decisions about what to teach than how to teach it. You don't want to teach things which the learner has already mastered, for that would be a waste of time and money, and it would demotivate the learner. On the opposite extreme, you don't want to teach things which are too far beyond the learner's current knowledge, for lack of important prior knowledge (including prerequisite skills -- [5] would make learning very difficult, if not impossible. The whole notion of "debugging" is basically a matter of deciding what to teach.

Perhaps the most important way that the nature of the learner influences the selection of instructional strategies is in making decisions about the amount of instructional support provided to the learner -- that is, how rich the instruction should be. It is important to assess the difficulty of the content based on the learner's ability and prior familiarity with it. The more difficult it is, the richer the instruction needs to be, including the use of more examples and practice, alternative representations (especially hands-on and visuals), attention-focussing devices, hints, and shaping (or successive approximations). A second way that the nature of the learner is important is in the selection of motivational strategies. A motivational profile of the learner is very important for selecting appropriate motivational strategies [6,7].

2.2 New Technologies

Clearly, instructional strategy prescriptions do not depend solely on the type of learning. Significant strides in information technologies are providing educational technologists with tools of a magnitude of power previously undreamed of. Most current instructional strategies were developed out of a "page" mentality. To take full advantage of the capabilities of new mediational systems, our thinking must advance beyond such a static, confining level. We need prescriptions which take advantage of the dynamic, interactive, and AI (Artificial Intelligence) capabilities of computers and interactive video.

Computer-based simulations possess great potential as one of the most powerful forms of instruction currently possible. But most simulations fall miserably short of their potential. Prescriptions for improving their quality are sorely needed. We recently completed a two-year project to develop such prescriptions [15]. But much more work remains to be done to test, refine, and further develop such prescriptions. I expect we will see considerable advances in this area over the next decade.

Advances in information technologies have also made possible the design of intelligent tutoring systems which can be used alone or in combination with simulations or other instructional approaches. Collins and Stevens [4] have identified a variety of strategies which are relatively unique to intelligent tutoring systems, including prescriptions for goal-setting, tracing consequences to a contradiction, and entrapping the student. The next decade should see continued advances in this important area.

2.3 Structure and Sequence

Another kind of prescription in great need of further development is how to structure and sequence a course or curriculum. Based on our efforts to synthesize the state of the art in this area, we have found considerable evidence that every pattern of sequencing is based on a single type of relationship within the content [14]. The chronological sequence is based on the time relationship among events, Gagné's hierarchical sequence is based on the learning prerequisite relationship among skills, the "forward-chaining" procedural sequence is based on the order relationship among activities, our elaboration theory's conceptual elaboration sequence is based on the "parts" or "kinds" taxonomic relationships among concepts, Scandura's shortest-path sequence (further developed and popularized by Paul Merrill) is based on the simple-to-complex relationship among paths of a procedure, and so forth.

We know relatively little about the kinds of relationships that are most important for a sequence to follow to maximize such goals as building stable cognitive structures, facilitating creative thought, and allowing for maximum appropriate learner control. New approaches to sequencing will probably be particularly important for generic skills, understanding, and effective learning. It seems likely that optimal sequencing "strands" will be developed for each of these types of learning, then interwoven with each other to form a complete course or curriculum sequence. As was mentioned earlier, we developed some prescriptions for doing this in our K-6 science project with Macmillan. We have continued this work on a project to redesign a course at Ithaca College [2], and we have found it easier than anticipated to integrate different strands to form a course sequence. Additional work is sorely needed in this area, and hopefully we will see much progress over the next decade.

Another dimension of structure is teaching the structure of a discipline to a learner. Synthesis is the process of explicitly teaching the relationships among ideas. Very little attention has been paid to developing useful prescriptions in this area. In our work on integrating prescriptions for macro methods, we have identified a variety of types of "pervasive" relationships -- relationships which exist on a continuing basis, such as "A is a kind of B, which is a kind of C, which is a kind of D...," and "M causes N, which causes O, which causes P..." see e.g., [16]. But these may be only the "tip of the iceberg" in relation to all the important kinds of relationships to teach. Again, this should be a fruitful area for future work.

2.4 Mediational Systems

Given that our field has strong roots in media, we have a tendency to constrain our instructional designs to certain mediational systems, particularly to such resources as print, computers, and video. However, it is helpful to keep in mind that many other types of mediational systems can be used. We should keep in mind that the source of instruction can be human or nonhuman, that a human source can be a professional or an amateur, that a nonhuman source can be instructionally designed or not created specifically for purposes of instruction, and that the intended receiver can be an individual or a group. These characteristics yield the kinds of mediational systems shown in figure 5.1.

		Source			
		Human		Nonhuman	
		Professional	Amateur	Designed	Natural
Receiver	Individual	Tutoring	Peer Tutoring	Individualized Resources	Individual Projects
	Group	Lecture	Discussion	Group Activities	Group Projects

Fig.5.1. Eight kinds of mediational systems as defined by the nature of the source and receiver. The cell labels are merely the closest fit with the concept as defined by the nature of the source and receiver.

Please note that the labels in the boxes are familiar concepts that do not overlap completely with the concept as defined by the characteristics of the source and receiver. Furthermore, almost any medium (or combination of media) can be used within each of these categories. Instructional designers have had a tendency to use individualized resources without considering that another mediational system might be better. Cost-benefit analysis is likely to be very important in making informed decisions. This is another important new direction for educational technology.

2.5 Instructional-Management Systems

As instructional tools become more powerful and more varied, the task of managing the instruction becomes more formidable -- and more important. It is not just a matter of coordinating diagnosis-and-revision activities, although that is certainly very important. It is also a matter of deciding which kind of resource is important for whom and when, and which strategies are important for whom and when on each resource. A wide variety of considerations comes into play, including individual differences, mastery learning, record keeping, learner control, scheduling, incentives, and much more.

With the development of expert systems, it is possible to think of designing an "advisor" into computer-based instruction -- an advisor which will monitor the learner's Activities, intervene with advice when appropriate, answer questions about instructional management, and serve other instructional management functions. But what are the rules which should govern such an advisor? And what instructional management activities are best left to a human? These are important areas for work in the next decade.

2.6 Motivating Learners

There is increasing recognition of the importance of motivating learners. Motivational strategies were largely ignored by instructional theorists until very recently. John Keller has done excellent work to integrate the current knowledge about motivation into a set of prescriptions for instructional designers, but more work is needed in this area, particularly regarding motivational strategies which are uniquely possible with advanced technologies.

3. Designer Tools

The development of expert systems has made possible the creation of powerful tools to increase the productivity and quality of instructional designers' efforts. But, as with intelligent tutors, we need to operationalize our instructional prescriptions as a highly detailed set of rules before we can create such tools. We also need to find out the extent to which such expert systems can actually design the instruction for a designer versus serve as a job aid to help the designer do it. Furthermore, given the need for a designer to work with a subject-matter expert to design instruction, should another expert system replace the subject-matter expert? If so, how should the two expert systems be interfaced? Dave Merrill has made some progress in answering these questions [10], but much work remains to be done in this area.

4. Applications

Finally, with respect to applications (contexts), the field has shifted dramatically in the past ten years to an emphasis on corporate training, with lesser increases being registered for health education, government training, and various adult education contexts. Public schools are currently receiving relatively little attention. I expect this to change considerably over the next ten years, initially with work on textbook and courseware design and evaluation, but eventually with work on teacher training as well. But this will not be easy. We are finding that our powerful new learning tools are not being adopted by school systems the way they can and should be, because the structure of the school system works against it.

But even more important is the increasing recognition that the problems with our schools are ones which cannot be fixed by providing more of everything: more teacher training, more teacher pay, more school hours in a day, more school days in a year, and so forth. For a quantum improvement in education, we need to develop a better system [3].

With our field's emphasis on systems thinking, we are uniquely qualified within schools of education to help public schools to restructure, and along with this unique qualification comes a certain responsibility. Our field is beginning to awaken to this responsibility, as is demonstrated by the recent special issue of the Journal of Instructional Development on Instructional Development in the schools (Vol. 10, No. 4). At Indiana University we have recently become involved in helping the Indiana Department of Education to plan better ways to structure the Indiana public schools to meet the needs of an information society. And Bela Banathy [1] has been working on ways to bring about systems changes in the schools. But our knowledge base is woefully inadequate in this area. I hope we will see important advances here over the next decade.

In sum, I feel that the most important new directions for research in educational technology include advancing our instructional strategy prescriptions for:

1) Facilitating understanding, generic skills application, and affective learning,
2) Utilizing the unique capabilities of new technologies,
3) Structuring and sequencing a course or curriculum,
4) Selecting mediational systems,
5) Designing instructional-management systems, and
6) Motivating learners.

Other important new directions include:

7) Developing expert systems as job aids for, or even replacements for, instructional designers, and
8) Providing more help to the public schools, especially by applying systems thinking to the design of structural features that are more appropriate for the educational needs of an information society.

These kinds of advances in our knowledge base are not going to be easy to achieve. They are going to require vision and resources, communication and cooperation. But whatever the obstacles, those advances are strategically crucial for helping us to strengthen the most important economic resource in an information society: the knowledge of our people.

References

1. Banathy, B.H. Systems inquiry in education. *Systems Practice,* 1 (2), 193-211. 1988.
2. Beissner, K., & Reigeluth, C.M. Course sequencing with multiple strands using the elaboration theory. *Paper presented at the meeting of the Association for Educational Communications and Technology*, Dallas, TX. 1989.
3. Branson, R.K. Why the schools can't improve: The upper limit hypothesis. *Journal of Instructional Development*, 10 (4), 15-26. 1987.
4. Collins, A., & Stevens, A.L. A cognitive theory of inquiry teaching. In C.M. Reigeluth (Ed.), *Instructional-design theories and models: An overview of their current status.* Hillsdale, NJ: Lawrence Erlbaum. 1983.
5. Gagné, R.M. *The conditions of learning and theory of instruction* (4th ed.). New York: Holt, Rinehart & Winston. 1985.
6. Keller, J.M. Motivational design of instruction. In C.M. Reigeluth (Ed.), *Instructional-design theories and models: An overview of their current status.* Hillsdale, NJ: Lawrence Erlbaum. 1983.
7. Keller, J.M. Development and use of the ARCS model of motivational design. *Journal of Instructional Development,* 10 (3), 2-10. 1987.
8. Martin, B.L, & Briggs, L.J. *The affective and cognition for instruction and research.* Englewood Cliffs, NJ: Educational Technology Publications. 1986.
9. Merrill, M.D. The new component design theory: instructional design for courseware authoring. *Instructional Science,* 16 (1), 19-34. 1987.
10. Merrill, M.D. Knowledge engineering an instructional design expert system. Workshop presented at the meeting of the *Association for Educational Communications and Technology*, Dallas, TX. 1989.
11. Reigeluth, C.M. A model of instruction for understanding. *Paper presented at the meeting of the Association for Educational Communications and Technology*, Dallas, TX. 1989a.
12. Reigeluth, C.M. Educational technology at the crossroads: New mind-sets and new directions. *Educational Technology Research & Development,* 37 (1), 67-80. 1989b.
13. Reigeluth, C.M. Sequencing and integrating cognitive strategies with subject-matter content. *Paper presented at the meeting of the Association for Educational Communications and Technology*, Dallas, TX. 1989c.
14. Reigeluth, C.M. Prescriptions for designing a theoretical elaboration sequence. Paper presented at the meeting of the *Association for Educational Communications and Technology*, Dallas, TX. 1989d.
15. Reigeluth, C.M., & Schwartz, E. A prescriptive theory for the design of computer-based educational simulations. *Journal of Computer-based Instructional Systems*, 16 (1). (1989, winter).
16. Reigeluth, C.M., & Stein, F.S. The elaboration theory of instruction. In C.M. Reigeluth (Ed.), *Theories and models: an overview of their current status.* Hillsdale, NJ: Erlbaum Associates. 1983.