Cognitive Flexibility, Constructivism, and Hypertext:
Random Access Instruction for
Advanced Knowledge Acquisition in Ill-Structured Domains

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INTRODUCTION: THE COMPLEX CONTEXT OF LEARNING AND THE DESIGN OF INSTRUCTION

A central argument of this paper is that there is a common basis for the failure of many instructional systems. The claim is that these deficiencies in the outcomes of learning are strongly influenced by underlying biases and assumptions in the design of instruction which represent the instructional domain and its associated performance demands in an unrealistically simplified and well-structured manner. We offer a constructivist theory of learning and instruction that emphasizes the real-world complexity and ill-structuredness of many knowledge domains. Any effective approach to instruction must simultaneously consider several highly intertwined topics, such as:

- the constructive nature of understanding;
- the complex and ill-structured features of many, if not most, knowledge domains;
- patterns of learning failure;
- a theory of learning that addresses known patterns of learning failure.

Based on a consideration of the interrelationships between these topics, we have developed a set of principled recommendations for the development of instructional hypertext systems to promote successful learning of difficult subject matter (see Spiro, Coulson, Feltovich, & Anderson, 1988; Spiro & Jehng, 1990). This systematic, theory-based approach avoids the ad hoc character of many recent hypertext-based instructional programs, which have too often been driven by intuition and the power of the technology.

In particular, we argue that:

- Various forms of conceptual complexity and case-to-case irregularity in knowledge domains (referred to collectively as ill-structuredness) pose serious problems for traditional theories of learning and instruction.

Cognitive and instructional neglect of problems related to content complexity and irregularity in patterns of knowledge use leads to learning failures that take common, predictable forms. These forms are characterized by conceptual oversimplification and the inability to apply knowledge to new cases (failures of transfer).

The remedy for learning deficiencies related to domain complexity and irregularity requires the inculcation of learning processes that afford greater cognitive flexibility: this includes the ability to represent knowledge from different conceptual and case perspectives and then, when the knowledge must later be used, the ability to construct from those different conceptual and case
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representations a knowledge ensemble tailored to the needs of the understanding or problem-solving situation at hand.

For learners to develop cognitively flexible processing skills and to acquire contentive knowledge structures which can support flexible cognitive processing, flexible learning environments are required which permit the same items of knowledge to be presented and learned in a variety of different ways and for a variety of different purposes (commensurate with their complex and irregular nature).

The computer is ideally suited, by virtue of the flexibility it can provide, for fostering cognitive flexibility. In particular, multidimensional and nonlinear hypertext systems, if appropriately designed to take into account all of the considerations discussed above, have the power to convey ill-structured aspects of knowledge domains and to promote features of cognitive flexibility in ways that traditional learning environments (textbooks, lectures, computer-based drill) could not (although such traditional media can be very successful in other contexts or for other purposes). We refer to the principled use of flexible features inherent in computers to produce nonlinear learning environments as Random Access Instruction (Spiro & Jehng, 1990).

- Following our injunction to consider all crucial issues in the learning and instruction environment jointly, we will develop the following compound argument, which integrates the claims presented above:

Characteristics of ill-structuredness found in most knowledge domains (especially when knowledge application is considered) lead to serious obstacles to the attainment of advanced learning goals (such as the mastery of conceptual complexity and the ability to independently use instructed knowledge in new situations that differ from the conditions of initial instruction). These obstacles can be overcome by shifting from a constructive orientation that emphasizes the retrieval from memory of intact preexisting knowledge to an alternative constructivist stance which stresses the flexible reassembly of preexisting knowledge to adaptively fit the needs of a new situation. Instruction based on this new constructivist orientation can promote the development of cognitive flexibility using theory-based hypertext systems that themselves possess characteristics of flexibility that mirror those desired for the learner.

In summary: Ill-structured aspects of knowledge pose problems for advanced knowledge acquisition that are remedied by the principles of Cognitive Flexibility Theory. This cognitive theory of learning is systematically applied to an instructional theory, Random Access Instruction, which in turn guides the design of nonlinear computer learning environments we refer to as Cognitive Flexibility Hypertexts.
Selective Focus on Advanced Knowledge Acquisition in Ill-Structured Domains

The argument developed in this paper is not intended to cover all aspects of constructive mental processing. Similarly, instructional technology is a broad topic that will not be exhaustively addressed in this paper. Rather, we will focus on a set of issues implicated by consideration of some special instructional objectives (Merrill, 1983) and the factors contributing to their attainment. In particular, we will be concerned only with learning objectives important to advanced (post-introductory) knowledge acquisition: to attain an understanding of important elements of conceptual complexity, to be able to use acquired concepts for reasoning and inference, and to be able to flexibly apply conceptual knowledge to novel situations. Furthermore, we will consider only complex and ill-structured domains (to be defined below). This combination of ambitious learning goals and the un-obliging nature of characteristics associated with certain knowledge domains will be seen to present special problems for learning and instruction that call for special responses at the level of cognitive theory and related instructional interventions.

We will argue that one kind of hypertext approach is particularly appropriate for this constellation of features associated with the instructional context. The omission of other varieties of computer-based instruction from our discussion does not imply any negative evaluation of their merits. Indeed, in other instructional contexts the kinds of hypertexts we will discuss would be inappropriate (e.g., computer-based drill would be better suited to the instructional objective of memorizing the multiplication tables; see Jacobson & Spiro, 1994, for the presentation of a framework for analyzing instructional contexts to determine the choice of educational technologies).

In what follows, we wish to illustrate how a particular set of factors in the instructional context (including learning goals and the nature of the knowledge domain) and a set of observed learning deficiencies jointly lead to a recommended cognitive theory-based instructional approach.

THE NATURE OF ILL-STRUCTURED KNOWLEDGE DOMAINS AND PATTERNS OF DEFICIENCY IN ADVANCED KNOWLEDGE ACQUISITION

Ill-structured Knowledge Domains: Conceptual Complexity and Across-Case Irregularity

An ill-structured knowledge domain is one in which the following two properties hold: 1) each case or example of knowledge application typically involves the simultaneous interactive involvement of multiple, wide-application conceptual structures (multiple schemas, perspectives, organizational principles, and so on), each of which is individually complex (i.e., the domain involves conceptual complexity); and 2) the pattern of conceptual incidence and interaction varies substantially across cases nominally of the same type (i.e., the
domain involves across-case *irregularity*). For example, understanding a clinical case of cardiovascular pathology will require appreciating a complex interaction among several central concepts of basic biomedical science; and that case is likely to involve differences in clinical features and conceptual involvements from other cases assigned the same name (e.g., other cases of "congestive heart failure"). Examples of ill-structured domains include medicine, history, and literary interpretation. However, it could be argued that even those knowledge domains that are, in the main, more well-structured, have aspects of ill-structuredness as well, especially at more advanced levels of study (e.g., mathematics). Furthermore, we would argue that all domains which involve the application of knowledge to unconstrained, naturally occurring situations (cases) are substantially ill-structured. For example, engineering employs basic physical science principles that are orderly and regular in the abstract and for textbook applications (Chi, Feltovich, & Glaser, 1981). However, the *application* of these more well-structured concepts from physics to "messy" real-world cases is another matter. The nature of each engineering case (e.g., features of terrain, climate, available materials, cost, etc.) is so complex and differs so much from other cases that it is difficult to categorize it under any single principle, and any *kind* of case (e.g., building a bridge) is likely to involve different patterns of principles from instance to instance. Similarly, basic arithmetic is well-structured, while the process of applying arithmetic in solving "word problems" drawn from real situations is more ill-structured. For example, consider the myriad ways that arithmetic principles may be signaled for access by different problem situations and problem wordings.

**Advanced Knowledge Acquisition: Mastery of Complexity and Preparation for Transfer**

The objectives of learning tend to differ for introductory and more advanced learning. When first introducing a subject, teachers are often satisfied if students can demonstrate a superficial awareness of key concepts and facts, as indicated by memory tests that require the student only to reproduce what was taught in roughly the way that it was taught. Thus, in introductory learning, ill-structuredness is not a serious problem. Learners are not expected to master complexity or independently transfer their acquired knowledge to new situations. These latter two goals (mastery of complexity and transfer) become prominent only later, when students reach increasingly more advanced treatments of the same subject matter. It is then, when conceptual mastery and flexible knowledge application become paramount goals, that the complexity and across-case diversity characteristic of ill-structured domains becomes a serious problem for learning and instruction.

**Patterns of Advanced Learning Deficiency in Ill-Structured Domains and Remedies in "Cognitive Flexibility Theory"**
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In this section we briefly review two related bodies of research: the nature of learning failures in advanced knowledge acquisition and new theoretical approaches to more successful advanced learning and instruction. 

Forms of a “reductive bias” in deficient advanced knowledge acquisition. Advanced knowledge acquisition, that very lengthy stage between introductory treatments of subject matter and the attainment of expertise for the subject, has been very little studied (certainly in comparison to the large number of studies of novices and experts--e.g., Chase & Simon, 1973; Chi et al., 1981; Feltovich, Johnson, Moller, & Swanson, 1984). However, in our own recent investigations of advanced learning in ill-structured domains, we have found a number of notable results, some of which were somewhat surprising (Coulson, Feltovich, & Spiro, 1989; Feltovich, Spiro, & Coulson, 1989; Myers, Feltovich, Coulson, Adami, & Spiro, 1990; Spiro, Feltovich, Coulson, & Anderson, 1989). These results may be summarized as follows:

Failure to attain the goals of advanced knowledge acquisition is common. For example, when students are tested on concepts that are consensually judged by teachers to be of central importance and that have been taught, conceptual misunderstanding is prevalent.

A common thread running through the deficiencies in learning is oversimplification. We call this tendency the reductive bias, and we have observed its occurrence in many forms. Examples include the additivity bias, in which parts of complex entities that have been studied in isolation are assumed to retain their characteristics when the parts are reintegrated into the whole from which they were drawn; the discreteness bias, in which continuously dimensioned attributes (like length) are bifurcated to their poles and continuous processes are instead segmented into discrete steps; and the compartmentalization bias, in which conceptual elements that are in reality highly interdependent are instead treated in isolation, missing important aspects of their interaction (see Coulson et al., 1989; Feltovich et al., 1989; Myers et al., 1990; Spiro et al., 1989 for presentations and discussion of the many reductive biases that have been identified). Of course, the employment of strategies of this kind is not a problem if the material is simple in ways consistent with the reductive bias. However, if real complexities exist and their mastery is important, such reduction is an inappropriate oversimplification.

Errors of oversimplification can compound each other, building larger scale networks of durable and consequential misconception.

- The tendency towards oversimplification applies to all elements of the learning process, including cognitive strategies of learning and mental representation, and instructional approaches (from textbooks to teaching styles to testing). These various sources of simplification bias reinforce each other (e.g., one is more likely to oversimplify if an inappropriately easier learning strategy is also employed in textbooks or teaching because it is simple).
As we will see in the next section, more appropriate strategies for advanced learning and instruction in ill-structured domains are in many ways the opposite of what works best for introductory learning and in more well-structured domains. For example, compartmentalization of knowledge components is an effective strategy in well-structured domains, but blocks effective learning in more intertwined, ill-structured domains that require high degrees of knowledge interconnectedness. Instructional focus on general principles with wide scope of application across cases or examples works well in well-structured domains (this is one thing that makes these domains well-structured), but leads to seductive misunderstandings in ill-structured domains, where across-case variability and case-sensitive interaction of principles vitiates their force. Well-structured domains can be integrated within a single unifying representational basis, but ill-structured domains require multiple representations for full coverage. For example, consider one kind of single unifying representation, an analogy to a familiar concept or experience. We have found that a single analogy may help at early stages of learning, but actually interfere with more advanced treatments of the same concept later on (Spiro et al., 1989; see also Burstein & Adelson, 1990). Any single analogy for a complex concept will always be limited in its aptness, and misconceptions that will develop when the concept is treated more fully can be predicted by knowing the ways in which the introductory analogy is misleading about or under-represents the material to be learned. To summarize, we have found that the very things that produce initial success for the more modest goals of introductory learning may later impede the attainment of more ambitious learning objectives.

There is much that appears to be going wrong in advanced learning and instruction (see also GPEP, 1984; Perkins & Simmons, 1989). The cognitive theories and instructional practices that work well for introductory learning and in well-structured domains not only prove inadequate for later, more advanced treatments of the same topics, but adherence to those theories and practices may produce impediments to further progress. Our conclusion is that a reconceptualization of learning and instruction is required for advanced knowledge acquisition in ill-structured domains (see also Spiro et al., 1987, 1988, 1989; Spiro & Jehng, 1990; Feltovich, Spiro, & Coulson, in press). Such a reconceptualization, taking into account the problems posed by domain ill-structuredness and the patterns of advanced learning deficiency observed in our studies, is presented next, in our discussion of constructivism and a new constructive orientation, Cognitive Flexibility Theory. After a brief survey of the tenets of that theory, we show its implications for the design of computer hypertext learning environments that are targeted to the features of difficulty faced by advanced learners in ill-structured domains.

CONSTRUCTIVISM, OLD AND NEW: COGNITIVE FLEXIBILITY THEORY AND THE PROMOTION OF ADVANCED KNOWLEDGE ACQUISITION

The topic of this special issue of Educational Technology is constructivism. Our interpretation of this term, as it is applied to learning and instruction, is complex.
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We argue that there are different points in cognitive acts where constructive mental processes occur. First, we take it as an accepted cognitive principle that understanding involves going beyond the presented information. For example, what is needed to comprehend a text is not solely contained in the linguistic and logical information coded in that text. Rather, comprehension involves the construction of meaning: the text is a preliminary blueprint for constructing an understanding. The information contained in the text must be combined with information outside of the text, including most prominently the prior knowledge of the learner, to form a complete and adequate representation of the text’s meaning (see Spiro, 1980, for a review; also see Ausubel, 1968; Bartlett, 1932; Bransford & Johnson, 1972; and Bruner, 1963).

However, our approach to constructivist cognition goes beyond many of the key features of this generally accepted view (see Spiro et al., 1987). The interpretation of constructivism that has dominated much of cognitive and educational psychology for the last 20 years or so has frequently stressed the retrieval of organized packets of knowledge, or schemas, from memory to augment any presented information that is to be understood or any statement of a problem that is to be solved. We argue that conceptual complexities and across-case inconsistencies in ill-structured knowledge domains often render the employment of prepackaged (“precompiled”) schemas inadequate and inappropriate. Rather, because knowledge will have to be used in too many different ways for them all to be anticipated in advance, emphasis must be shifted from the retrieval of intact knowledge structures to support the construction of new understandings, to the novel and situation-specific assembly of prior knowledge drawn from diverse organizational loci in preexisting mental representations. That is, instead of retrieving from memory a previously packaged “prescription” for how to think and act, one must bring together, from various knowledge sources, an appropriate ensemble of information suited to the particular understanding or problem solving needs of the situation at hand. Again, this is because many areas of knowledge have too diverse a pattern of use for single prescriptions, stored in advance, to cover enough of the cases that will need to be addressed. (For other discussions of issues related to cognitive flexibility and “inert knowledge,” see Bereiter & Scardamalia, 1985; Bransford, Franks, Vye, & Sherwood, 1989; Brown, 1989; and Whitehead, 1929.)

Thus, in Cognitive Flexibility Theory, a new element of (necessarily) constructive processing is added to those already in general acceptance, an element concerned primarily with the flexible use of preexisting knowledge (and, obviously, with the acquisition and representation of knowledge in a form amenable to flexible use). (However, also see Bartlett’s, 1932, notion of “turning round upon one’s schema.”) This "new constructivism" is doubly constructive: 1) understandings are constructed by using prior knowledge to go beyond the information given; and 2) the prior knowledge that is brought to bear is itself constructed, rather than retrieved intact from memory, on a case-by-case basis (as required by the across-case variability of ill-structured domains). (Also see Bereiter, 1985.)

Cognitive Flexibility Theory is a "new constructivist" response to the difficulties of advanced knowledge acquisition in ill-structured domains. It is an integrated theory of learning, mental representation, and instruction. We now turn our
attention to that theory. (Having discussed the relationship of Cognitive Flexibility Theory to constructivism, the latter term will not be used explicitly very often in the remainder of the paper -- but it should be understood that when we talk about Cognitive Flexibility Theory, we are referring to a particular constructivist theory.)

**Cognitive Flexibility Theory: A Constructivist Approach to Promoting Complex Conceptual Understanding and Adaptive Knowledge Use for Transfer**

Limitations of space will not permit a detailed treatment of the key features of Cognitive Flexibility Theory in this section. Let it suffice to say that the tenets of the theory are direct responses to the special requirements for attaining advanced learning goals, given the impediments associated with ill-structured features of knowledge domains and our findings regarding specific deficiencies in advanced learning -- knowing what is going wrong provides a strong clue for how to fix it. In lieu of any comprehensive treatment, we will discuss here one central aspect of the theory. Then, we will show how that aspect creates implications for the design and use of hypertext learning environments. For more detailed treatments of Cognitive Flexibility Theory, see Spiro et al. (1987, 1988), Spiro and Jehng (1990) and Feltovich et al. (in press).

The aspect of Cognitive Flexibility Theory that we will briefly discuss here and use for illustrative purposes involves the importance of **multiple juxtapositions of instructional content**. Some other aspects of the theory will be referred to in passing in the context of that discussion. (Many key tenets of Cognitive Flexibility Theory will not be mentioned at all; e.g., the vital importance of students’ active participation in learning). A central claim of Cognitive Flexibility Theory is that revisiting the same material, at different times, in rearranged contexts, for different purposes, and from different conceptual perspectives is essential for attaining the goals of advanced knowledge acquisition (mastery of complexity in understanding and preparation for transfer). Content must be covered more than once for full understanding because of psychological demands resulting from the complexity of case and concept entities in ill-structured domains, combined with the importance of contextually induced variability and the need for multiple knowledge representations and multiple interconnectedness of knowledge components (see Spiro et al., 1988, for justifications of all these requirements). Any single explanation of a complex concept or case will miss important knowledge facets that would be more salient in a different context or from a different intentional point of view. Some of the representational perspectives necessary for understanding will be grasped on a first or second exploration, while others will be missed until further explorations are undertaken. Some useful connections to other instructed material will be noticed and others missed on a single pass (with connections to nonadjacently presented information particularly likely to be missed). And so on. Revisiting material in an ill-structured domain is not a simple repetitive process useful only for forming more durable memories for what one already knows. For example, re-
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examining a case in the context of comparison with a case different from the comparison context (i.e., the first time the case was investigated) will lead to new insights (especially if the new "reading" is appropriately guided); this is because partially nonoverlapping aspects of the case are highlighted in the two different contexts. The more complex and ill-structured the domain, the more there is to be understood for any instructional topic; and therefore, the more that is unfortunately hidden in any single pass, in any single context, for any restricted set of purposes, or from the perspective of any single conceptual model. For example, consider the importance of multiple knowledge representations, which is one thing made possible by multiple passes through the same material. A key feature of ill-structured domains is that they embody knowledge that will have to be used in many different ways, ways that can not all be anticipated in advance. Knowledge that is complex and ill-structured has many aspects that must be mastered and many varieties of uses that it must be put to. The common denominator in the majority of advanced learning failures that we have observed is oversimplification, and one serious kind of oversimplification is looking at a concept or phenomenon or case from just one perspective. In an ill-structured domain, that single perspective will miss important aspects of conceptual understanding, may actually mislead with regard to some of the fuller aspects of understanding, and will account for too little of the variability in the way knowledge must be applied to new cases (Spiro et al., 1989). Instead, one must approach all elements of advanced learning and instruction with the tenet of multiple representations at the center of consideration.

Cognitive Flexibility Theory makes specific recommendations about multiple approaches that range from multiple organizational schemes for presenting subject matter in instruction to multiple representations of knowledge (e.g., multiple classification schemes for knowledge representation). Knowledge that will have to be used in a large number of ways has to be organized, taught, and mentally represented in many different ways. The alternative is knowledge that is usable only for situations like those of initial learning; and in an ill-structured domain that will constitute just a small portion of the situations to which the knowledge may have to be applied.

Given all of this, it should not be surprising that the main metaphor we employ in the instructional model derived from Cognitive Flexibility Theory (and in our related hypertext instructional systems) is that of the criss-crossed landscape (Spiro et al., 1987; Wittgenstein, 1953), with its suggestion of a nonlinear and multidimensional traversal of complex subject matter, returning to the same place in the conceptual landscape on different occasions, coming from different directions. Instruction prepares students for the diversity of uses of ill-structured knowledge, while also demonstrating patterns of multiple interconnectedness and context dependency of knowledge, by criss-crossing the knowledge domain in many ways (thereby also teaching students the importance of considering complex knowledge from many different intellectual perspectives, tailored to the context of its occurrence). This should instill an epistemological belief structure appropriate for ill-structured domains and provide a repertoire of flexible knowledge representations that can be used in constructing assemblages of
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knowledge, taken from here and from there, to fit the diverse future cases of knowledge application in that domain.

**CONSTRAINTS ON THE DESIGN OF HYPERTEXT LEARNING ENVIRONMENTS DRAWN FROM IMPLICATIONS OF COGNITIVE FLEXIBILITY THEORY**

Thus far, we have discussed the relationship between the nature of ill-structured knowledge domains and difficulties in the attainment of advanced learning goals (mastery of complexity and transfer to new situations). A principle of Cognitive Flexibility Theory was then introduced as one antidote to the problems of advanced knowledge acquisition in ill-structured domains. Now, we will briefly point to some of the ways that these cumulative considerations impinge on the design and use of hypertext learning environments.

First, the preceding discussion should make it reasonably clear that hypertext environments are good candidates for promoting cognitive flexibility in ill-structured domains. We have referred to the need for rearranged instructional sequences, for multiple dimensions of knowledge representation, for multiple interconnections across knowledge components, and so on. Features like these correspond nicely to well known properties of hypertext systems, which facilitate flexible restructuring of instructional presentation sequences, multiple data codings, and multiple linkages among content elements. It appears straightforward that a nonlinear medium like hypertext would be very well suited for the kinds of "landscape criss-crossings" recommended by Cognitive Flexibility Theory (and needed in ill-structured knowledge domains; see also Bednar, Cunningham, Duffy, & Perry, 1991).

However, it is not that easy. Implementing Cognitive Flexibility Theory is not a simple matter of just using the power of the computer to "connect everything with everything else." There are many ways that hypertext systems can be designed, and there is good reason to believe that a large number of those do not produce successful learning outcomes (e.g., because they lead the learner to become lost in a confusing labyrinth of incidental or ad hoc connections). What is needed is the discipline of grounding hypertext design in a suitable theory of learning and instruction. That is what we have done in several prototype hypertext systems derived from Cognitive Flexibility Theory and tailored to the known obstacles to advanced learning in difficult and ill-structured domains (Spiro et al., 1988; Spiro & Jehng, 1990). To provide some idea of how theory informs design, consider just one very simple example of a hypertext design decision that responds to an aspect of Cognitive Flexibility Theory-based logic discussed in the last section: rearrangement of the presentation sequence of content (that has been investigated previously), in order to produce different understandings when that content is "re-read."

**Illustrating the Theory- and Context-Based Logic of Hypertext Design**
Because of the feature of conceptual instability in ill-structured domains (i.e., the same conceptual structure takes on many more meanings across instances of its use than in well-structured domains), Cognitive Flexibility Theory dictates, as discussed in the last section, that one kind of instructional revisiting should produce an appreciation in the learner of the varieties of meaning "shades" associated with the diversity of uses. As Wittgenstein argued (1953), the meaning of ill-structured concepts is in their range of uses, rather than in generally applicable definitions--there is no simple "core meaning." We extend Wittgenstein's claim to larger units than the individual concept (e.g., complex conceptual structures such as a theme of a literary work). So, a feature built into our hypertexts is conceptual structure search: content is automatically re-edited to produce a particular kind of "criss-crossing" of the conceptual landscape that visits a large set of case examples of a given conceptual structure in use. The learner then has the option of viewing different example cases in the application of a concept he or she chooses to explore. That is, the instructional content is re-edited upon demand to present just those cases and parts of cases that illustrate a focal conceptual structure (or set of conceptual structures). Rather than having to rely on sporadic encounters with real cases that instantiate different uses of the concept, the learner sees a range of conceptual applications close together, so conceptual variability can easily be examined. Learning a complex concept from erratic exposures to complex instances, with long periods of time separating each encounter, as in natural learning from experience, is not very efficient. When ill-structuredness prevents telling in the abstract how a concept should be used in general, it becomes much more important to show together the many concrete examples of uses. In sum, a hypertext design feature is incorporated as a response to a learning difficulty caused by a characteristic of ill-structured knowledge domains. (Of course, the issue of example selection and sequencing in concept instruction has been dealt with before, e.g., Tennyson & Park, 1980. What is novel about the present approach is the particular way that this issue is addressed and the kinds of higher-order conceptual structures that are studied. Even more important is the fact that that single issue is addressed within a larger, integrative framework. That is, the treatment of conceptual variability is just one aspect of a complete approach in which the diverse aspects are theoretically united.)

Following this same kind of logic, we will sketch briefly some of the other ways that hypertext design features can be made to match the goals of advanced learning--under the constraints of domain ill-structuredness and according to the tenets of Cognitive Flexibility Theory. For this purpose we will use one of our Cognitive Flexibility Hypertext prototypes, Exploring Thematic Structure in Citizen Kane (Knowledge Acquisition in Nonlinear Environments--"KANE," for short; see Spiro and Jehng, 1990, for details), which teaches processes of literary interpretation in a post-structuralist mode (e.g., Barthes, 1967).

KANE is a learning environment that goes beyond typical instructional approaches to literary interpretation that too often settle on a single, integrative understanding ("The theme of Citizen Kane is X."). Instead, students are shown that literary texts (in this case a videodisc of a literary film) support multiple interpretations, the interpretations combine and interact, they take on varying
senses in different contexts, and so on. For example, the issue of conceptual variability that was discussed above is addressed by providing an option that causes the film to be re-edited to show just those scenes that illustrate any selected conceptual theme of the film (e.g., "Wealth Corrupts", "Hollow, Soulless Man", etc.). Using this option, the learner could, for example, see five scenes in a row, taken from various places in the film, that illustrate different varieties or "flavors" of the "Wealth Corrupts" theme. Each scene essentially forms a miniature case of the Kane character's behavior that illustrates the targeted theme. (Although the student is assumed to have already seen the film one or more times--this is advanced knowledge acquisition for Citizen Kane--the nonlinear presentation may still occasionally confuse. Therefore, to deal with this and other kinds of out-of-sequence criss-crossings, a design feature of Cognitive Flexibility Hypertexts is the provision of optional background information on the contexts immediately preceding the one being explored.) Because of the inability of abstract definitions (as might be construed for a theme such as "Soulless Man") to cover conceptual meanings-in-use in ill-structured domains, supplementary guidance about the way meaning is used in a particular situation (Brown, Collins, & Duguid, 1989) is required. This is provided for in KANE by giving the learner the option of reading an expert commentary on the special shade of meaning associated with the conceptual theme, as applied to a scene, immediately after the scene is viewed. These functional and context-sensitive (particularized) definitions explain why the scene is considered to be a case of a theme such as "Wealth Corrupts." Note that a particularized representation of meaning is not the same as a dictionary sense of a word: the latter refers to different sub-types of a word's meaning, but with an implied similarity or overlap across instances of the same type--so there is less need to tailor to the individual case; in contrast, particularizing, as we mean it, implies a representation of a concept that is necessarily expressed in terms of an instance of usage (case, example, scene, occasion of use), as required in an ill-structured domain. Commentaries also include information about knowledge access: what cues in the case context should provide a "tip-off" that a particular concept might be relevant for analyzing a case--if one can not access relevant conceptual information in memory, this knowledge will not be useful on subsequent occasions.

The commentaries also provide cross-references to other instantiations of the conceptual structure that constitute an instructionally efficacious set of comparisons (e.g., other cases/scenes in which either a roughly similar or saliently different particularized sense of that conceptual theme occurs). The guiding commentaries also include another important kind of cross-reference, namely to other conceptual themes that have interpretive relevance in accounting for the same case of Kane's behavior, concepts that interact with and influence the meaning of each other in that scene. (Note that these different kinds of cross-references counter the reductive tendencies toward compartmentalization of concepts and their cases of application that we have found to be harmful in advanced learning.) Thus there is a double particularization in Cognitive Flexibility Hypertexts: the generic conceptual structure is particularized not only to the context of a specific case, but also to the other concepts simultaneously applicable for analyzing that case. That is, each case or example is shown to be a
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complex entity requiring for its understanding multiple conceptual representations, with the role of non-additive conceptual interdependencies highlighted. Each of the conceptual themes used in KANE is itself a wide-scope interpretive schema that has been argued for in the secondary literature on the film as being the most important theme for understanding the character of Kane. In reality, however, an ill-structured domain has no single schema that is likely to cover everything of interest for an individual case, nor is any schema/theme/concept likely to dominate across a wide range of cases. Therefore, the greater the number of such broad-gauge schemata that are available (and KANE provides ten), the greater the utility for understanding in two senses. First, there will be adequate coverage of the complexity of an individual case by an appropriately diverse set of schemata (something which is also modeled in KANE by the simultaneous display of all the relevant conceptual themes in each scene). Second, the likelihood is increased that the most apt set of conceptual schemata will be cognitively available for understanding any one of the highly diverse new cases that will be encountered in an ill-structured domain--the more conceptual structures there are to choose from, each a powerful schema itself and each taught in its complex diversity of patterns of use, the greater the chance that you will find a good fit to a given case. A related virtue is that configurations of combinations of conceptual structures are thereby demonstrated; since multiple conceptual representations will be required for each instance of knowledge application, the ability to combine conceptual entities and to recognize common patterns of their combination is crucial. The process of situation-specific knowledge construction, so important for transfer in ill-structured domains, is thus supported in at least two important ways: the processes of adaptive knowledge assembly are demonstrated, and the flexible knowledge structures required for this assembly are acquired. Furthermore, as users of the program shift over time into more of a "free exploration" mode, where they independently traverse the themes of the film in trying to answer questions of interpretation (posed by teachers or themselves), their active participation in learning the processes of knowledge assembly increases.

Flexible tools for covering content diversity and for teaching knowledge assembly combine to increase the resources available for future transfer/application of knowledge (e.g., interpreting a scene that has not yet been viewed or assembling prior knowledge to facilitate comprehension of a critique written about the film). By making many potential combinations of knowledge cognitively available--either by retrieval from memory or by context-sensitive generation--the learner develops a rich palette to paint a knowledge structure well fit to helping understand and act upon a particular case at hand. This is especially important in an ill-structured domain because there will be great variety in the demands on background knowledge from case to case (and with each case individually rich in the knowledge blend required). This discussion could continue for many other features of hypertext learning environments that are specifically derived from Cognitive Flexibility Theory. What would be in common across any such discussion is that each feature could be shown to have the following purpose: to counter an advanced learning difficulty endemic to ill-structured domains.
CONCLUDING REMARKS
We have just discussed a few of the many kinds of revisitings of instructional content in rearranged contexts that are implied by Cognitive Flexibility Theory and embodied in our hypertext systems. However, our goals in this paper were necessarily limited. Our purpose was merely to begin to illustrate the way design features of a particular kind of computer learning environment are related to cognitive and instructional theories that are themselves based on the problems posed by the interaction of learning objectives and characteristics of ill-structured knowledge domains. That is, our intention was to illustrate a way of thinking about the design of hypertext learning environments that is sensitive to and dependent upon the cognitive characteristics necessary for advanced knowledge acquisition in ill-structured domains. In particular, these are the characteristics of the "new constructivism" that we discussed earlier and that are properties of Cognitive Flexibility Theory. The realm of constructive processes must be taken beyond the retrieval of knowledge structures from memory (for the purpose of "going beyond the information given" in some learning situation), to also include the independent, flexible, situation-specific assembly of the background knowledge structures themselves.

In sum, we consider our work to be moving towards a systematic theory of hypertext design to provide flexible instruction appropriate for developing cognitive flexibility. We have called the instructional theory that is derived from Cognitive Flexibility Theory and applied in flexible computer learning environments Random Access Instruction. It, and the developing hypertext theory, is laid out in considerable detail in Spiro and Jehng (1990). We are encouraged so far about the robustness, systematicity, and generality of our hypertext design principles, in that they have been applied in very similar ways to develop hypertext prototypes in domains as diverse as cardiovascular medicine, literary interpretation, and military strategy. Preliminary data on the effectiveness of these Cognitive Flexibility Hypertexts is also encouraging. For example, Jacobson and Spiro (1991) investigated two different design approaches for structuring a hypertext learning environment to provide instruction in a complex and ill-structured domain (the social impact of technology). The results of this experiment revealed that while the design which emphasized the mastery of declarative knowledge led to higher performance on measures of memory for presented facts, the design based on Cognitive Flexibility Theory (which highlighted different facets of the material by explicitly demonstrating critical interrelationships between abstract and case-centered knowledge components, in multiple contexts on different passes through the same content) promoted superior transfer to a new problem solving situation. More empirical testing is clearly required, and numerous other issues of hypertext design remain to be discussed. However, those are stories for another time.
AFTERWORD: SOME CLARIFYING THOUGHTS ON KNOWLEDGE REPRESENTATION, CONTENT SPECIFICATION, AND THE DEVELOPMENT OF SKILL IN SITUATION-SPECIFIC KNOWLEDGE ASSEMBLY

The stance taken by Cognitive Flexibility Theory on certain constructivist issues is somewhat unique and may be misinterpreted. To forestall that possibility, we discuss a few of those issues in this final section. (The fault for such misinterpretation of course rests with the expositors of the theory. Such was certainly the case for any misinterpretations by our discussants that resulted from our presentation at the conference upon which this volume is based.)

Cognitive Flexibility Theory and Objectivist versus Constructivist Conceptions of Knowledge: Multiple Knowledge Representations for Adequacy of Coverage and Preparation for Transfer

It is clear that there are many variations on what is meant by "constructivist." Accordingly, it may be useful to situate our position along the continuum of potential viewpoints. Our constructivist position, as it applies to complex and ill-structured domains, rejects any view that says either that there is no objective reality, or that there is an objective reality that can be "captured" in any single and absolute way. Rather, one of our principal tenets is that the phenomena of ill-structured domains are best thought of as evincing multiple truths: single perspectives are not false, they are inadequate. That is why multiple knowledge representations are so central to Cognitive Flexibility Theory. And it is why the multidimensional and nonlinear "criss-crossing" of conceptual and case landscapes, to demonstrate the context-dependent diversity of warranted and valid understandings (where there is more than one right answer, it is not a matter of "anything goes" -- candidate understandings must be justified), is so important a feature of Cognitive Flexibility Hypertexts (CFHs). In an ill-structured knowledge domain, individual cases can be reasonably interpreted from different conceptual perspectives, each adding something useful that the others miss. And the domain as a whole will be inadequately characterized by any fixed organization of superordinate and subordinate conceptual structures (given the variability across cases in the relative importance of concepts in the domain). To be ready to use knowledge flexibly, to be able to find the most useful of the valid representations to fit the needs of a particular case, one must have available a diverse repertoire of ways of constructing situation-sensitive understandings (again, with appropriate justification required). In an ill-structured domain, any overly limited version of what is "correct" will miss too much of the complexity that must be mastered for sufficiency of rich conceptual understanding and fullness of case coverage. This point is crucial and worth restating: single (monolithic, "total"), prespecifiable truths will not account for enough of the across-case variability and individual case complexity that is a hallmark of ill-structuredness. As we have said in other places, knowledge that will have to be
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used in many ways, as will be the case in ill-structured domains, must be taught and mentally represented in many ways.

Prespecification of Knowledge and the Teaching of Content versus Skill: Cognitive Flexibility Hypertexts Provide Building Blocks for Flexible, Situation-Sensitive Knowledge Assembly, Not Final Products of Knowledge

Related to the issue of multiple knowledge representations are the topics of prespecification of knowledge and the teaching of content versus skill. It could be argued that an important difference between our position and that of other constructivists is that we prespecify the knowledge that students should learn. This could be considered a drawback of our approach, indicating an overly objectivist nature. The point about prespecifeciability is also related to the possible misunderstanding that we teach domains of knowledge (i.e., content), not skills of thinking. These characterizations are not entirely accurate. CFHs do not fully prespecify the knowledge that will be presented to learners, and the instructional philosophy of Cognitive Flexibility Theory is very much oriented towards the development of the special cognitive processing skills needed in ill-structured domains (as well as providing an exploration environment which can foster the apprehension of content and structural relationships useful for the learner to represent).

There is some prespecification in our systems. However, we would not say that the representation of the knowledge that we want learners to acquire is fully and explicitly contained in the knowledge base of a CFH. What is prespecified is not some final product of knowledge that learners are supposed to passively assimilate. Rather, CFHs provide exploration environments, organized around building blocks for knowledge assembly, that are useful for a process of constructivist thinking that is inculcated. A corollary of our argument that complex and ill-structured knowledge domains require multiple representations is that any single case of the use of knowledge in such a domain will require a selective assembly of appropriate subsets of those representational perspectives that must be appropriately integrated to fit the needs of the particular situation at hand. Accordingly, the extent of knowledge prespecification found in CFHs is limited to rough guideposts or starting points for thinking about the domain, with an emphasis on their flexibility rather than rigidity of structuration and use. The more extended treatments of our approach make it clear that what is impressed upon the learner is that the knowledge guidelines that are provided do not have prespecified meanings, definable in the abstract and in advance of their application in diverse contexts (e.g., see Spiro et al., 1988; Spiro & Jehng, 1990). Instead, meaning is partially determined by rough patterns of family resemblance and then filled out by interactions of those patterns with details of their specific contexts of use (Wittgenstein, 1953). It is for the learner to construct understandings that grasp these patterns of family resemblance and context-dependency; CFHs assist in this learner-based constructive activity.
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For example, although CFHs provide widely applicable themes of conceptual understanding, these instructional programs emphasize the variability of a theme's meaning across cases (e.g., by demonstrating how those conceptual structures receive specific tailorings in individual case contexts and interact with other concepts in the shaping of meaning). With so much variability and context-dependency of "meaning", the limits of prespecifiability become quite evident. So, the theme search option in CFHs (discussed earlier) causes cases to be successively displayed that instantiate a given conceptual theme; however, the commentaries for each case stress the specialized aspects of the concept's use in that context, as well as interrelations with other conceptual themes in each case's unique environment. And by seeing so wide a range of uses for the same conceptual theme juxtaposed to each other, the idea that a teacher could hand a student some prespecified, general, core meaning is clearly disabled—the student sees that it is, in the end, his or her job to build meaning.

Thus, we follow a "middle road" between rigid prespecification (with rigid prestructuring and rigid prescription of routines for knowledge use), and associated passive reception by the learner (with a memory emphasis), at one extreme, and immersion in a totally unstructured environment, neglectful of the role of conceptual aspects of understanding, at the other extreme. Furthermore, we definitely advocate active participation of the learner, faded control from the "teacher" (e.g., the computer program) to the student as learning proceeds (Collins, Brown, & Newman, 1989), and (as suggested by Thompson, this volume, and implemented in current versions of CFHs) options that permit customization by the learner to go beyond even the loose prestructuring that we provide (e.g., options to add conceptual themes and case analyses).

We question the aptness of the term "prespecification" to describe the nature of the information presented to students in CFHs. When so many safeguards are built into CFHs to make it likely that learners will not look for an exact specification of the knowledge they should acquire (that they could then passively record in memory), we would prefer to say that the opportunity to learn flexible foundations for building case-dependent specifications on their own is provided to them. In sum, where flexibility and openness of potential warranted interpretations are avowed as primary virtues of both system design and the intended cognitive structures and processes of students using the system, as they are in CFHs, we do not believe "prespecification" is an apt descriptor. If one considers the kinds of things CFHs teach (again, see our cited papers), and how they are taught, it should be clear that the prespecification is minimal, and that the goal is for students to develop an epistemological stance which treats knowledge as substantially not prespecifiable in ill-structured domains. CFHs are like intellectual "erector sets" that, by permitting open-ended exploration in the context of some flexible background structures, aspire to the goals of making knowledge a manipulable, "three-dimensional" entity for the learner, and providing the tools for creating knowledge arrangements for different purposes.

Finally, the issue of prespecifiability is related to the question of whether our emphasis is on the teaching of content or the inculcation of skills (see Dick, 1991). Here too, our stance is clear: We argue that where there is so much richness of
potential understanding and so much variability across individually complex cases of knowledge application, that a central role must be accorded to situation-sensitive knowledge assembly. This is because in an ill-structured domain the manner of use of knowledge varies too much across situations to be specified in advance and then retrieved intact from memory. Thus, CFHs would be useless in preparing learners to apply their knowledge widely to new cases (the learning objective of transfer) if they did not teach both the constructive learning skills of context-dependent, multidimensional, noncompartmentalized knowledge acquisition, and the constructive application skills of flexible, situation-sensitive knowledge assembly (those skills that are characteristic of a particular domain and those that are of more general utility).

**Occasions for Cognitive Flexibility Hypertexts: Instructional Contexts for Nonlinear and Multidimensional Case-Based Learning**

Finally, we want to say again that we do not believe that CFHs are ideally suited for all instructional situations. As we have said in our papers (see the citations below), in well-structured knowledge domains, where the application of general principles and abstract concepts can proceed in a routinized manner (i.e., in roughly the same way across large numbers of cases), there is little need to prepare people for the kind of situation-specific knowledge assembly process that CFHs are intended to develop. Therefore, in well-structured knowledge domains it is not necessary to engage in so complicated an instructional process as the multidimensional and nonlinear "landscape criss-crossing" employed in CFHs.2 We have been explicit about the kinds of knowledge domains for which CFHs should be used and the learning objectives they are intended to foster. CFHs are for case-based instruction in complex and ill-structured domains for the purposes of advanced knowledge acquisition, i.e., mastery of complexity and development of the ability to flexibly apply or transfer knowledge to a wide range of new, real-world cases.

An instructional approach should be no more complicated than it needs to be. However, instruction must be as complicated as is necessary to achieve the established goals of learning, given the constraints imposed by the features of the knowledge domain that is the subject of learning. We have found in our studies of advanced knowledge acquisition that initial simplifications of complex subject areas can impede the later acquisition of more complex understandings (Feltovich, Spiro, & Coulson, 1989; Spiro et al., 1989). CFHs offer an approach to instruction in which learners can be presented relatively early on (following as brief an introductory segment as possible) with features of complexity necessary for advanced understanding in a domain, providing a foundation that can be built upon as still more advanced treatments of the material are presented. And this (necessary) early introduction of some complexity is accomplished in a tractable manner made possible by a new approach to incremental instructional sequencing designed to minimize the extent to which students become overwhelmed by difficult subject matter they need to master.
In this context, it is interesting to note that sometimes people argue that there is something inconsistent about our having a well-structured theory of learning in ill-structured domains. The idea that there is something wrong with an orderly and coherent discussion of the issues faced by learning in disorderly domains is a logical error. The domain and the theory of the domain are different things. One can have a well formed theory of learning in ill-structured domains that provides systematic ways of increasing respect for and attention to a domain's complexity—that is what Cognitive Flexibility Theory does.

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Notes

1 This point is relevant to a potential misunderstanding: Inevitably, there are superficial similarities that disguise quite fundamental differences between the CFH approach and more traditional ones. The relationship between how CFHs and other instructional design approaches use ‘examples’ is illustrative of this point. It might seem at first blush that our conceptual-theme-search option is intended to highlight defining features of a concept’s application, in the way traditional instructional design makes use of examples. However, we do not provide examples of a concept’s use. We teach from rich, real-world cases, demonstrating a process by which case features and the context of other relevant concepts in the case influence conceptual application. Although it may appear that we are teaching concepts and abstract principles, we are in fact doing something quite different. We are teaching cases most centrally (because of the considerable across-case irregularity that characterizes ill-structured domains), and the ways in which concepts get woven through and tailored to the case contexts of their occurrence. In this sense, it becomes less relevant to ask, for example, how many examples we recommend presenting to a student. Each “example” is actually a complete case “experience” in itself; the more cases you encounter, the greater the amount of experience and the richer the understanding. In other words, our answer to the question “How many?” is “The more the better” (but you learn an awful lot just from a case or two -- see Spiro & Jehng, 1990, for an example of how much can be learned from just a brief scene from a larger case). Furthermore, in a CFH the student revisits the same case in different contexts, to teach different lessons; it is not clear how a revisiting should be “counted.” Advanced knowledge acquisition is very often not a discrete process with a finite endpoint; rather, knowledge must be cultivated and continuously developed -- the more you interact with sources of knowledge, the more you learn. In sum, this brief discussion should make it clear that the imputation of similarity across instructional philosophies should be made
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with great caution. (This is not to say that there are not important affinities between the CFH approach and, say, that of Merrill (1991). We believe that there are, along with some important points of divergence.)

2 See Jacobson & Spiro (1994) for a discussion of a proposed framework for analyzing instructional contexts to determine the kind of educational technology approach (e.g., drill and practice; intelligent tutoring system; hypertext) best suited to the context. It should also be noted that we believe ill-structuredness to be far more prevalent than is typically believed, especially with increasingly more advanced treatments of subject matter and in any domain of knowledge application in unconstrained real-world settings, such as the professions.

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