Siegel, M., Derry, S., Kim, J.B., Steinkuehler, C., Street, J., Canty, N., Fassnacht, C., Hewson, K., Hmelo, C., & Spiro, R. (2000). Promoting Teachers' Flexible Use of the Learning Sciences through Case-Based Problem Solving on the WWW: A Theoretical Design Approach. In B. Fishman & S. O'Connor-Divelbiss (Eds.), *Fourth International Conference of the Learning Sciences* (pp. 273-279). Mahwah, NJ: Erlbaum.

Promoting Teachers' Flexible Use of the Learning Sciences through Case-Based Problem Solving on the WWW: A Theoretical Design Approach

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Abstract: The Secondary Teacher Education Project is involved in building scientific principles of web-based instructional design. The general question being addressed is how to most effectively support learning within complex web sites that contain many pages of conceptual material tied to real-world problems and/or cases. Cognitive Flexibility Theory provides useful principles for how to design such web sites. The goal of our site is to help middle school through college teachers acquire *useful* scientific knowledge about student learning and development--knowledge that can be applied flexibly to the design and management of productive classroom learning environments. In this paper, we describe our (a) theory-based approach to design and (b) site implementation and lessons learned from user testing.

Keywords: learning theory; professional development; computer-mediated communication; teacher learning.

Designing Complex Web Sites to Enhance Useful Knowledge

The World Wide Web provides an increasingly important medium for delivering all levels and forms of training and instruction. Developing and managing large, complex web sites are daily tasks for many training organizations, as well as individual professors and teachers. While there are several new commercial software systems that can help educators support this work (WebCT, for example), few of those systems have been developed or examined from the perspective of current scientific principles of learning theory. Some systems provide tremendous instructional design flexibility, but little guidance about how that flexibility should best be used to promote student learning.

At its broadest level, this project is about building scientific understanding of web-based instructional design. The general question being addressed is how to most effectively support learning within web sites that contain many pages of conceptual material tied to real-world problems and/or cases. Case-based instruction (CBI) refers to an approach in which students are exposed to subject-matter knowledge as they study and analyze cases, which are often experts' solutions to real-world problems. Similarly, in problem-based learning (PBL), students in working groups learn subject matter as required for solving real-world problems. CBI and PBL problems are typically ill-structured and complex--designed to mimic life. The two approaches are gaining popularity and are frequently combined in instructional settings, both on and off the web, in professional (e.g., legal, business, and medical) education as well as K-16 settings to help students acquire *useful knowledge* (Hmelo & Williams, 1998).

The phrase *useful knowledge* emphasizes an ambitious goal for knowledge transfer, namely, the recall and use of knowledge acquired in one context (e.g., school) within another context (e.g., the workplace). Non-trivial knowledge transfer has been an elusive goal for education; researchers, instructional developers, and knowledgeable educators eagerly seek ways to obtain it. Yet, studies by cognitive psychologists and anthropologists have repeatedly shown that non-trivial knowledge transfer is surprisingly difficult to achieve (Brown, Collins & Duguid, 1989; Cormier & Hagman, 1987; Saloman & Perkins, 1989).

The premise of our work is that a high level of transfer might be attained through web-based instructional design that supports case- and problem-based instruction and learning. Little is known about how to design such instructional web sites effectively. This paper will describe our general design principles and the solutions we have generated so far.

Introduction to STEP Web

We are building, evaluating, and disseminating a particular instructional web site called STEP Web (http://www.wcer.wisc.edu/step), a professional development environment on the World Wide Web for pre- and in-service teachers. Resources on STEP Web include: access to *video* cases of actual classroom practice; instructional *problems* and projects that promote scientific analysis of the cases; a network of case-relevant links to core *concepts* from cognitive psychology and other learning sciences; access to expert case analyses and live human *expertise*; links to on-line case *discussions*; and links to tools and *resources* that teachers can use for their own instructional design projects.

The goal of STEP Web is to help middle school through college teachers acquire *useful* scientific knowledge about student learning and development--knowledge that can be applied flexibly to the design and management of productive classroom learning environments. The web-based medium is chosen to provide the broadest possible international access to professional development materials and practices that are grounded in current knowledge about learning and development.

Cognitive Flexibility Theory: Basis for Web Design

A good design is needed to guide case-based exploration of a complex web. Otherwise, teacher users would likely conduct many unproductive searches. Beginning users in particular would not be expected to conduct efficient searches for materials and ideas, if only given the key words or indices that might be used by a regular search engine. Hence, the web site itself must facilitate user navigation in support of case-based inquiry learning.

A scientific theory about how to design such web sites is Cognitive Flexibility Theory (CFT) (e.g., Spiro, Feltovich, Jacobson & Coulson, 1991), which pertains to instructional design in complex and irregular domains where advanced understanding and real-world problem solving capability are desired. A central argument of CFT is that many instructional approaches fail because they represent complex subject matter in an unrealistically simplified and well-structured manner. The remedy for learning deficiencies related to domain complexity requires instructional designs that afford greater cognitive flexibility:

> this includes the ability to represent knowledge from different conceptual and case perspectives and then, when knowledge must later be used, the ability to construct from those different conceptual and case representations a knowledge ensemble tailored to the needs of the understanding or problem-solving situation at hand (Spiro et al., 1991, p. 24).

The developers of CFT suggest that multidimensional and non-linear hypertext systems have the power to convey knowledge complexity and to promote features of cognitive flexibility. CFT was developed a decade ago to inform design of hypertext environments. Today it is relevant to web site design. Appropriate domains for the application of CFT include professional-level education, such as medical and teacher education. The CFT approach is based on the steps in Figure 1. As shown, a problem-solving domain is defined, a library of real cases is constructed, and a knowledge base is developed that includes information and other resources for understanding and analyzing the cases. Finally, web links and navigational strategies are designed to guide movement through the knowledge web while interacting with the cases. These links represent the criss-crossed network of interactive conceptual relationships among cases and ideas within a domain. Navigational strategies, which influence how students negotiate the complex conceptual web terrain, should encourage students to construct multiple understandings for cases and use domain concepts and perspectives repeatedly in case analysis, in different combinations.

CFT predicts that this type of learning strategy will enhance flexible knowledge use and transfer of learning to real-world contexts (Spiro, et al., 1991). The CFT design can be contrasted with more traditional course and textbook designs, which tend to be hierarchical and linear in structure and navigation of material. Despite the powerful hypertext capabilities of the World Wide Web, many instructional sites continue to reflect a traditional hierarchical approach, modified only by extended page-linking capabilities.

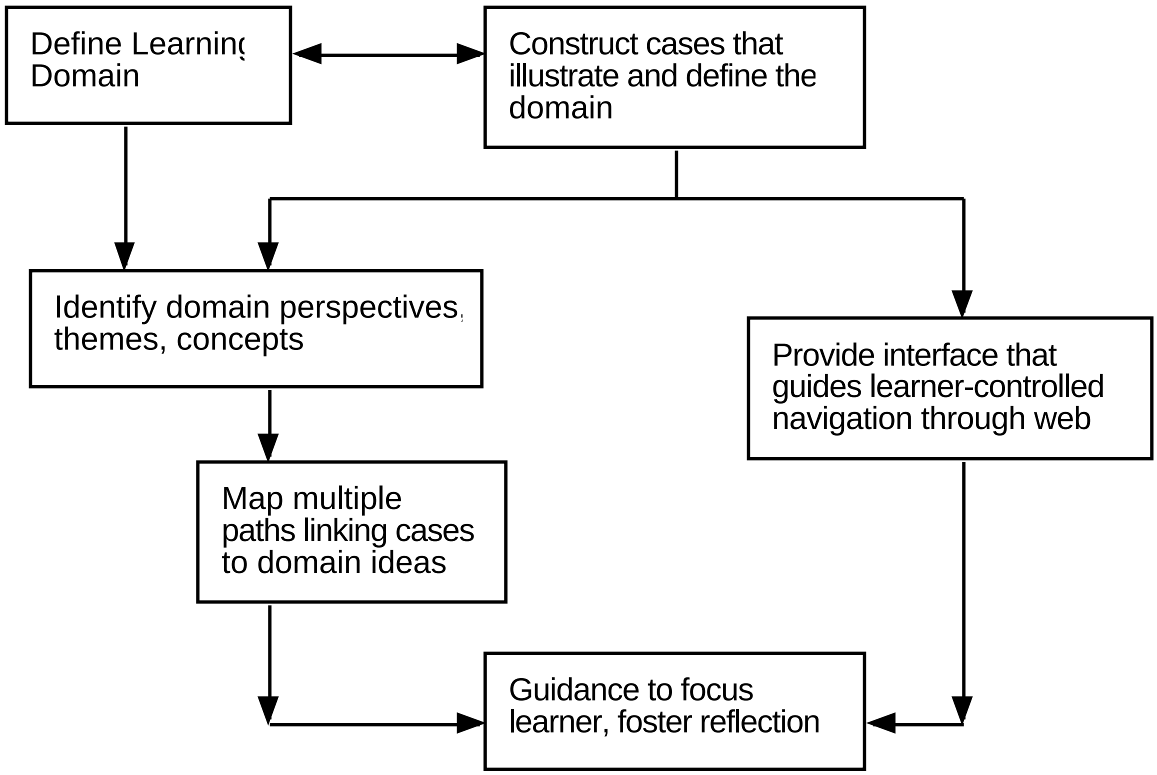

Figure 1. Knowledge web design with Cognitive Flexibility Theory.

Implementation of the STEP Web Site

Our current version of STEP Web is being developed using the open-source web-development tool ZOPE (Digital Creations, 1999). ZOPE is an object-based system that helps produce and manage large web sites. Its power lies in helping bring such sites up quickly and allowing many people to keep the site organized and updated without undue effort. ZOPE appears to have capabilities conducive to instructional web design in accordance with CFT.

We are developing the conceptual content of STEP Web in large chunks called idea families. The first idea family represents cognitive theory and deals with information processing and a sociocognitive approach to teaching and learning. (Figure 2 shows a partial page from the sociocognitive section.) The second idea family includes sociocultural analyses of teaching and learning, and a third takes a cross-theory approach, emphasizing views on assessment, knowledge construction, and classroom management. These idea families represent the theoretical perspectives that currently drive educational research appearing in the most respected scientific journals. A fourth family will be designed to help teachers examine popular educational “bandwagons” from a scientific perspective. For example, what does the research really say about the right-brain/left-brain approaches?

Use of the STEP Site

An example of an instructional use of STEP Web follows. In their science methods course, teacher-education students are placed in teams and asked to solve Problem Case 1, “Students Get a Charge out of Static Electricity." This case, presented as readings, videos, and inquiry materials, tells the story of a science unit taught in a large public high school. It represents a good case of traditional, teacher-centered instruction (see Figure 3). The problem for the pre-service student team is to redesign the instructional plan of the unit, within practical constraints, from multiple learning-sciences perspectives and justify that redesign in scientific terms. As an example, Figure 2 shows part of a page about cognition that students can learn about. Students post their team's redesign and explanation on a web conference site for peer evaluation and consultation with experts, including scientists and educational experts.

Of course there is not one "correct" scientific analysis or instructional design approach for any classroom case. Each can legitimately be viewed from many points of view. No case has a unique solution and every case analysis is unique. Experts in instructional psychology typically combine many different concepts to create a unique "situation model" of a case, which is then used as a basis for reasoning and instructional design. Teachers, however, have great difficulty seeing how different psychological concepts can be combined to model and evaluate a real classroom situation (Schulman, 1987). One student commented, for instance, "Well, when I *first* saw the video…I really didn't see any problems with Mr. Johnson's classroom. I actually thought that he was doing a pretty good job. Then after watching a few more times I realized what he was doing wrong. Essentially, this has taught me to always take a *second* look at what I will be doing in my classroom…." We also have observed that this difficulty occurs even when teachers have performed well in a formal course in instructional psychology.

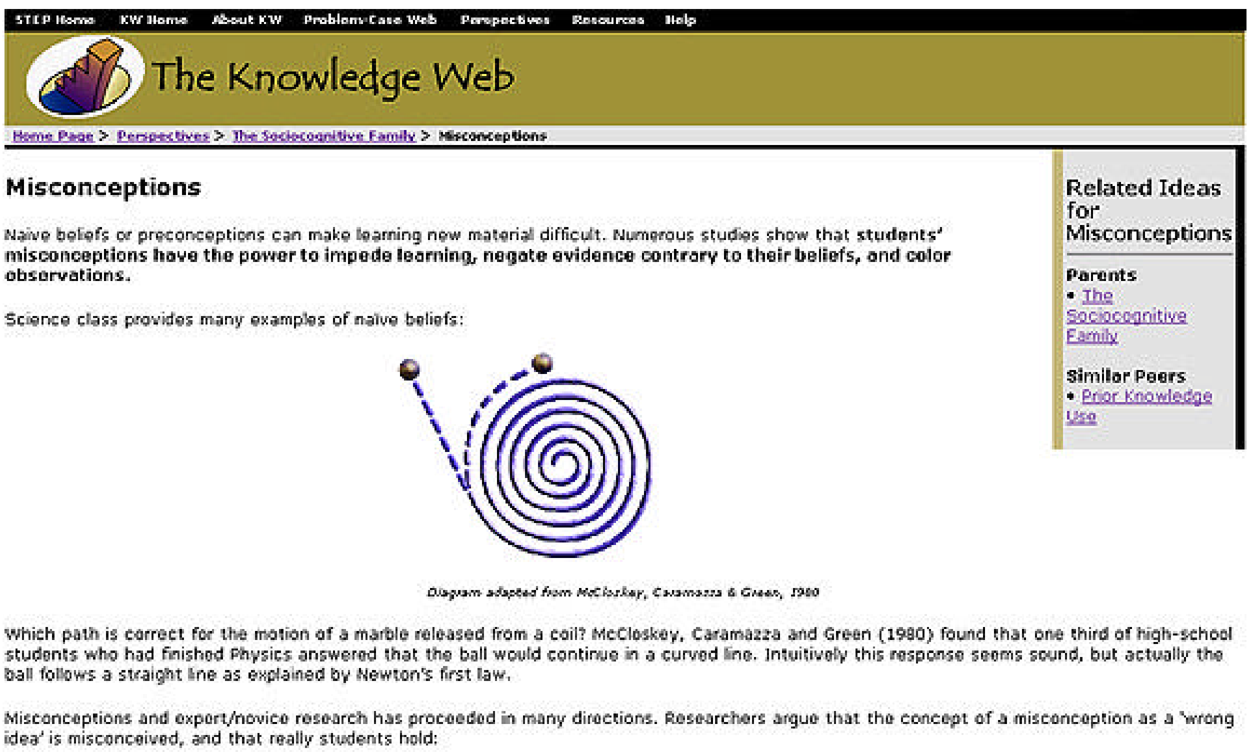

Figure 2. Part of the "misconceptions" page from the conceptual web.

Figure 3. Excerpt from a video case.

Using STEP Web problem cases, pre- and in-service teachers, as students, are expected to discuss and argue about design solutions and search the Step Web for relevant information. This process, supported in STEP Web through the links attached to every case, should engender useful knowledge according to previous CBI (Kleinfeld, 1991; Kolodner, 1997; McNergney, Herbert & Ford, 1994; Merseth, 1991) and PBL (Albanese & Mitchell, 1993; Norman & Schmidt, 1992) research. By exploring links, users obtain case-relevant concepts and materials that expose different points of view and invite further exploration.

Here is an excerpt from one group's final paper:

> One of the first mistakes Mr. Johnson [alias] made was that he assumed his students already had prior knowledge on static electricity. As Mr. Johnson aimlessly asked his students questions, they blurted out answers that showed they had no prior knowledge of how protons and electrons interact.
>
> The first thing Mr. Johnson should have done was to introduce the unit on static electricity by asking the students what they already knew about static electricity. We suggest that Mr. Johnson create a concept map using what the students already know about static electricity from their other classes or everyday lives. "Prior knowledge is stored in the form of schemas. Teachers can activate these schemas in a number of ways including: reviewing, questioning, or developing with the students a concept map of prior knowledge" (STEP Web). A concept map is extremely important because "teachers use students' prior knowledge to explain and discuss increasingly more sophisticated concepts. Prior knowledge becomes a platform upon which new understanding is constructed (STEP Web). The prior knowledge the students have becomes a building block or a foundation for new knowledge. When the students are done explaining to Mr. Johnson what they previously know about static electricity, we suggested he give a brief lecture to fill in all the gaps and add to the concept map what the students missed. The new knowledge the students learn from the lecture provide them with an integral tool that will allow them to make more meaningful connections when they see the experiment.

Lessons Learned

We are currently engaged in a process of formative evaluation and iterative, user-centered development of STEP Web using teacher education students and teaching assistants as subjects. As a result, we can now share a number of lessons regarding the creation of web-based CFT sites for case-based problem solving.

In terms of interface design, for example, we have discovered that when using a family metaphor for organizing the conceptual network, the structure of the network--representing relations among ideas--changes somewhat from case to case. That is, different family structures are required for different problem-solving contexts, even when the ideas are held constant across cases. Participants also stated a preference for multiple paths to reach a certain concept and asked for the site to be "cross-referenced."

In terms of instructional design, we learned from our trials that subjects prefer to read about the learning sciences concepts when they are related to the video case problems with which they are engaged. Participants also tended to navigate the site by centering around the case page rather than by surfing from concept to concept. However, when other participants were asked to browse the site before solving the problem, they requested more guidance about the cognitive science content. It would be helpful to require users to follow the conceptual links from the case page in order to structure their introduction to the learning sciences.

In addition, students did not automatically turn to the inquiry links that contained further information about the case. Students had to be reminded that certain things might be helpful, such as the physics chapter, when they had no physics knowledge. This additional guidance might have been needed because there was not yet a standard case schema with expectations for particular kinds of available information. If a standard case schema for items is not present, instruction during early cases that is faded for later cases might suffice.

Only 2/6 of the student-teacher groups in one pilot study went beyond fairly traditional solutions to the instructional redesign problem. However, this was the first time they had experience using multiple theories to frame their ideas. Multiple theories did show up as learning issues (concepts they needed to learn more about) for groups, even though they were not as evident in the final papers. All groups referenced the STEP web site in their papers. Further trials will add to our strategies for helping teachers acquire useful knowledge about the learning sciences.

Future Steps

STEP Web contains video cases, training exercises that use cases, expert case analyses and problem solutions, and text (web pages) explicitly linked to cases and explaining case-relevant psychological concepts. Many questions remain regarding how these resources should be designed, integrated and deployed during instruction to produce the desired learning outcomes--cognitive transfer and flexibility. Future experimental research will address the following issues: How should expert case analyses, case-based problem exercises and conceptual content on web pages be combined during instruction to promote desirable learning outcomes? How should the individual components of instruction (cases, problems, and web pages) be designed to facilitate learning? How can instructional environments help students to process case-based instruction effectively, so that performance is enhanced?

Another important strand of future research will involve developing and experimentally testing alternative navigational strategies. The problem of navigation is associated with (dis)orientation in the hyper-space represented by a complex web site. Three basic categories of solutions have been proposed: 1. Those involving development of tools to support navigation (backtracking, bookmarks, guided tours, navigation maps, history lists); 2. those involving interface and navigational metaphors, including virtual metaphors; and 3. solutions involving hardware (e.g., Dias et al., 1999). The ZOPE software we are currently using supports a particular metaphor based on family relationships among concepts. We are interested in perfecting this metaphor and testing it against alternative navigational strategies that incorporate advanced visualization techniques. Further experimentation will add to our evolving design principles for developing complex web sites that support the acquisition of useful knowledge.

References

Albanese, M. & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. Academic Medicine, 68, 52-81.

Brown, J.S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18, 32-42.

Cormier, S. & Hagman, J. (1987). *Transfer of Learning*. San Diego, CA: Academic Press.

Dias, P., Gomes, M.J., & Correia, A.P. (1999). Disorientation in hypermedia environments: Mechanisms to support navigation. *Journal of Educational Computing Research*, 20(2), 93-117.

Digital Creations, Inc. (1999). Zope is available from the website www.zope.org as of 10/22/99.

Hmelo, C. E. & Williams, S. M. (1998). Special Issue: Learning Through Problem Solving. *The Journal of the Learning Sciences*, 7.

Kleinfeld, J. (1991). Changes in problem solving abilities of students taught through case methods. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago.

Kolodner, J. (1997). Educational implications of analogy: A view from case-based reasoning. *American Psychologist*, 52(1): 57-66.

McNergney, R.F., Herbert, J.M., & Ford, R.E. (1994). Cooperation and competition in case-based teacher education. *Journal of Teacher Education,* 45, 339-345.

Merseth, K.K. (1991). The case for cases in teacher education. Washington, DC: American Association for Higher Education and American Association of Colleges for Teacher Education.

Norman, G.R. & Schmidt, H.G. (1992). The psychological basis of problem-based learning: A review of the evidence. *Academic Medicine*, 67, 557:565.

Saloman, G. & Perkins, D.N. (1989). Rocky road to transfer: Rethinking mechanisms of a neglected phenomenon. *Educational Psychologist,* 24, 113-142.

Schulman, L.S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review,* 57 (1), 1-22.

Spiro, R.J., Feltovich, P.J., Jacobson, M. & Coulson, R.L. (1991). Cognitive flexibility, constructivism and hypertext: Advanced knowledge acquisition in ill-structured domains. *Educational Technology*, 31(5), 24-33.

Acknowledgements

This research was conducted through the National Institute for Science Education, which is a partnership of the University of Wisconsin-Madison and the National Center for Improving Science Education, Washington, DC, with funding from the National Science Foundation (Cooperative Agreement No. RED-9452971). However, the ideas expressed herein are not endorsed by and may not be representative of positions endorsed by the sponsoring agencies. We would like to gratefully acknowledge recent developers, researchers and teachers: Brian Beitzel, Julia Lee, Young Ju Lee, Julie Posselt, Jenna Seymour, Brian Viola, and Paul Feltovich.