10 Designing Constructivist Learning Environments[1]

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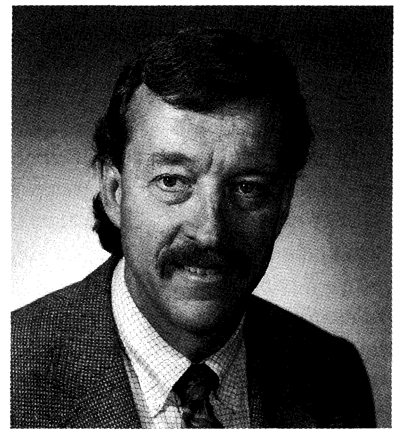

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[1]In order to conform to the structure of this book, the design of constructivist learning environments (CLEs) is described conceptually in an objectivist way in this chapter. That is not my preference. In my classes, students define or accept a problem first and learn how to design CLEs in the context of that problem. However, any competent objectivist instruction (including this chapter) is obligated to provide examples. Page limitations prevent this, as well as a full elaboration of the model and its theoretical foundations. So CLE prototypes and environments can be examined elsewhere (http://www.ed.psu.edu/~jonassen/CLE/CLE.html).

FOREWORD

Goals and preconditions*. The primary goal of this theory is to foster problem solving and conceptual development. It is intended for ill-defined or ill-structured domains.*

Values*. Some of the values on which this theory is based include:*
- *learning that is driven by an ill-defined or ill-structured problem (or question, case, project),*
- *a problem or learning goal that is "owned" by the learner,*
- *instruction that consists of experiences which facilitate knowledge construction (meaning making),*
- *learning that is active and authentic.*

Methods*. Here are the major methods this theory offers:*
1. *Select an appropriate problem (or question, case, project) for the learning to focus on.*
   - *The problem should be interesting, relevant and engaging, to foster learner ownership.*
   - *The problem should be ill-defined or ill-structured.*
   - *The problem should be authentic (what practitioners do).*
   - *The problem design should address its context, representation, and manipulation space.*
2. *Provide related cases or worked examples to enable case-based reasoning and enhance cognitive flexibility.*
3. *Provide learner-selectable information just-in-time.*
   - *Available information should be relevant and easily accessible.*
4. *Provide cognitive tools that scaffold required skills, including problem-representation tools, knowledge-modeling tools, performance-support tools, and information-gathering tools.*
5. *Provide conversation and collaboration tools to support discourse communities, knowledge-building communities, and/or communities of learners.*
6. *Provide social/contextual support for the learning environment.*

This theory also offers the following instructional activities to support learning:

A. *Model the performance and the covert cognitive processes.*
B. *Coach the learner by providing motivational prompts, monitoring and regulating the learner's performance, provoking reflection, and/or perturbing learners' models.*
C. *Scaffold the learner by adjusting task difficulty, restructuring the task, and/or providing alternative assessments.*

Major contribution*. The integration of much work in the constructivist arena into a coherent instructional framework.*

—C.M.R.

Designing Constructivist Learning Environments

INTRODUCTION

Objectivist conceptions of learning assume that knowledge can be transferred from teachers or transmitted by technologies and acquired by learners. Objectivist conceptions of instructional design include the analysis, representation, and resequencing of content and tasks in order to make them more predictably and reliably transmissible.

Constructivist conceptions of learning, on the other hand, assume that knowledge is individually constructed and socially coconstructed by learners based on their interpretations of experiences in the world. Since knowledge cannot be transmitted, instruction should consist of experiences that facilitate knowledge construction. This chapter presents a model for designing constructivist learning environments (CLEs) that engage learners in meaning making (knowledge construction). For an elaboration of the assumptions and beliefs on which CLEs are based, see Duffy and Jonassen (1992); Jonassen (1991, 1995a, 1995b, 1996a); Jonassen, Campbell, and Davidson (1994); Jonassen, Peck, and Wilson (1998); and Savery and Duffy (1996).

While objectivism and constructivism are usually conveyed as incompatible and mutually exclusive, that is not an assumption of this chapter. Rather, I believe that objectivism and constructivism offer different perspectives on the learning process from which we can make inferences about how we ought to engender learning. The goal of my writing and teaching is not to reject or replace objectivism. To impose a single belief or perspective is decidedly nonconstructivist. Rather, I prefer to think of them as complementary design tools (some of the best environments use combinations of methods) to be applied in different contexts.*

MODEL FOR DESIGNING CONSTRUCTIVIST LEARNING ENVIRONMENTS

The model for designing CLEs (Fig. 10.1) illustrates their essential components. The model conceives of a problem, question, or project as the focus of the environment, with various interpretative and intellectual support systems surrounding it. The goal of the learner is to interpret and solve the problem or complete the project.

* This diversity of perspectives and methods is an important aspect of the new paradigm of instructional theories.

Related cases and information resources support understanding of the problem and suggest possible solutions; cognitive tools help learners to interpret and manipulate aspects of the problem; conversation/collaboration tools enable communities of learners to negotiate and coconstruct meaning for the problem; and social/contextual support systems help users to implement the CLE.

1. Question/Case/Problem/Project

The focus of any CLE is the question or issue, the case, the problem, or the project that learners attempt to solve or resolve. It constitutes a learning goal that learners may accept or adapt. The fundamental difference between CLEs and objectivist instruction is that the problem drives the learning, rather than acting as an example of the concepts and principles previously taught. Students learn domain content in order to solve the problem, rather than solving the problem as an application of learning.

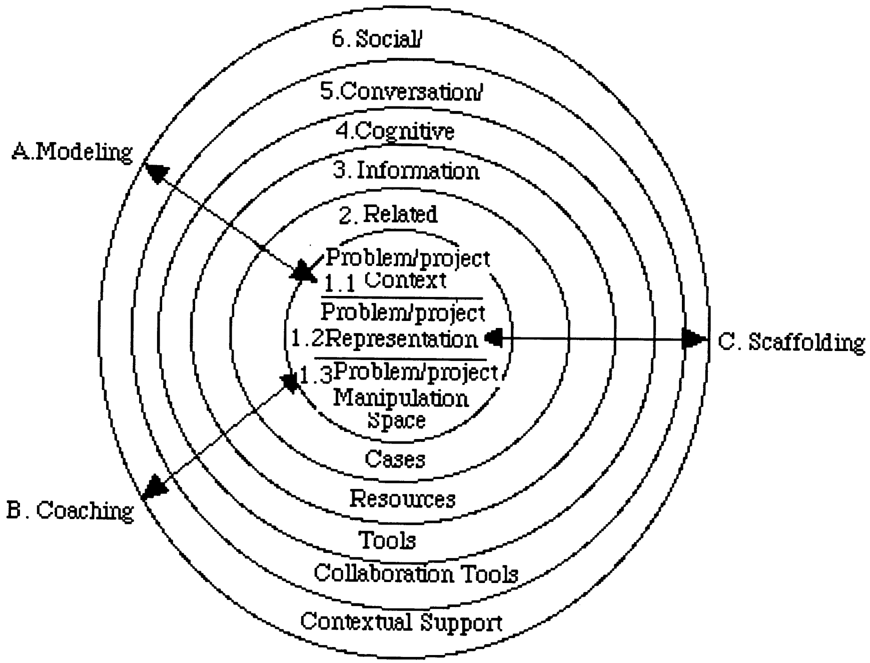

FIG. 10.1. Model for designing CLEs

CLEs can be constructed to support question-based, issue-based, case-based, project-based, or problem-based learning. Question- or issue-based learning begins with a question with uncertain or controversial answers (e.g., Should welfare recipients be required to work? Should environmental protection seek to eliminate pollution or regulate according to location-sustainable standards?). In case-based learning, students acquire knowledge and requisite thinking skills by studying cases (e.g., legal, medical, social work) and preparing case summaries or diagnoses. Case learning is anchored in authentic contexts; learners must manage complexity and think like practitioners (Williams, 1992). Project-based learning focuses on relatively long-term, integrated units of instruction where learners focus on complex projects consisting of multiple cases. They debate ideas, plan and conduct experiments, and communicate their findings (Krajcik, Blumenfeld, Marx, & Soloway, 1994). Problem-based learning (Barrows & Tamblyn, 1980) integrates courses at a curricular level, requiring learners to self-direct their learning while solving numerous cases across a curriculum. Case-, project-, and problem-based learning represent an approximate continuum of complexity,* but all share the same assumptions about active, constructive, and authentic learning. CLEs can be developed to support each of these, so for purposes of this chapter, which seeks to present a generic design model, I will refer to the focus of the CLEs generically as a problem.

Since the key to meaningful learning is ownership of the problem or learning goal, you must provide interesting, relevant, and engaging problems to solve.** The problem should not be overly circumscribed. Rather, it should be ill defined or ill structured, so that some aspects of the problem are emergent and definable by the learners. Why? Without ownership of the problem, learners are less motivated to solve or resolve it. Contrast ill-structured problems with most textbook problems, which require practice of a limited number of skills to find the correct answer without helping to shape or define the problem. Ill-structured problems, on the other hand:

- have unstated goals and constraints,
- possess multiple solutions, solution paths, or no solutions at all,
- possess multiple criteria for evaluating solutions,
- present uncertainty about which concepts, rules, and principles are necessary for the solution or how they are organized,
- offer no general rules or principles for describing or predicting the outcome of most cases, and
- require learners to make judgments about the problem and to defend their judgments by expressing personal opinions or beliefs (Jonassen, 1997).

* Interestingly, Schwartz, Lin, Brophy, and Bransford (chap. 9) viewed project-based learning as more complex than problem-based learning (p. 206). See if you can figure out why. Clearly, there can be a great range of complexity within each.

** The issues of motivation and ownership are consistent themes in the new paradigm.

How Can You Identify Problems for CLEs? Examine the field of study, not for its topics (as in a textbook) but for what practitioners do. You need only ask experienced practitioners to describe cases, situations, or problems that they have solved. Newspapers and magazines are replete with problems and issues that need resolution. Ask yourself, "What do practitioners in this field do?" In political science, students may construct a viable constitution for an emerging third world democracy that can accommodate the social, cultural, political, and historical characteristics of the population and their relationship with other countries in the region. In philosophy, render judgments on ethical dilemmas, such as right-to-die cases or same-sex marriages. In science, decide whether a local stream can accommodate a new sewage treatment plant. You need to evaluate all suggested problems for their suitability. Do your students possess prerequisite knowledge or capabilities for working on this problem? Do not assume that they will produce solutions as elegant or efficient as experienced practitioners. That is not the goal. Rather, the goal is to learn about the field by thinking like a member of that practice community.

Problems in CLEs need to include three integrated components: the problem context, the problem representation or simulation, and the problem manipulation space.* In order to develop a CLE, you should try to represent each in the environment.

1.1. Problem Context

An essential part of the problem representation is a description of the context in which it occurs. Tessmer and Richey (1997) have developed a conceptual model and set of processes for analyzing and mapping the physical, organizational, and sociocultural context in which problems occur. The same problem in different social or work contexts is different. CLEs must describe in the problem statement all of the contextual factors that surround a problem.

Performance Environment. You should describe the physical, socio-cultural, and organizational climate surrounding the problem. Where and in what time frame does it occur? What physical resources surround the problem? What is the nature of the business, agency, or institution in which the problem occurs? What do they produce? Provide annual reports, mission statements, balance sheets, and profit-and-loss statements if they appropriately describe the situation. What is the history of the setting? This information should be made available to learners in order to understand the problem.**

Community of Practitioners/Performers/Stakeholders. What are the values, beliefs, sociocultural expectations, and customs of the people involved? Who sets policy? What sense of social or political efficacy do the members of the setting or organization feel? What are the skills and performance backgrounds of performers?

* Here a general method is being broken down into three more detailed component methods.

** Here the component method is being further broken down into sub-components.

Provide resumes for key players that describe not only their experience, but also their hobbies, traits, and beliefs. You can also convey this information in stories or interviews with key personnel in the form of audio or video clips. It is the community of participants who define what learning occurs in a context. Learning is not an isolated event. Rather it is an incidental by-product of participation in that community (Lave & Wenger, 1991), so knowing what that community believes is important.

1.2. Problem Representation/Simulation

The representation of the problem is critical to learner buy-in. It must be interesting, appealing, and engaging. It must perturb the learner. The Cognition and Technology Group at Vanderbilt (1992)* insists on high-quality video scenarios for introducing the problem and engaging learners. Virtual reality may become the default method for representing problems soon. An effective, low-tech method for representing problems is narrative.** The problem context and problem representation become a story about a set of events that leads up to the problem that needs to be resolved. The narrative may be presented in text, audio, or video. Effective examples of narrative forms of problem representations are the instructional-design cases by Lindeman et al., (1996; see also http://curry.edschool.virginia.edu/go/ITCases/). In these cases, characters are developed who interact in realistic ways to introduce the case problem. Stories are also the primary means of problem representation and coaching in goal-based scenarios (Schank, Berman, & Macpherson, chap. 8 of this volume). The problem presentation simulates the problem in a natural context. Stories are a natural means for conveying them.

Authentic. Nearly every conception of constructivist learning recommends engaging learners in solving authentic problems.*** What is authentic? Some designers insist that authentic refers to supporting the performance of specific real-world tasks. This restrictive conception of authenticity will render learning environments that are authentic in a narrow context. Most educators believe that "authentic" means that learners should engage in activities which present the same type of cognitive challenges as those in the real world (Honebein, Duffy, & Fishman, 1993; Savery & Duffy, 1996), that is, tasks which replicate the particular activity structures of a context.

Activity structures rely on the socio-historical context of Activity Theory (Leontev, 1979), which focuses on the activities in which community members engage, the goals of those activities, the physical setting that constrains and affords

* See also chapter 9 by Schwartz, Lin, Brophy and Bransford in this volume.

** Notice that here the component method (problem representation) is being broken down into kinds, rather than parts. Presumably, different kinds of representations will be preferable for different situations, and it is those situationalities that make this a theory rather than just a model of instruction (see chap. 1, p. 21, in Volume 1).

*** Here it is more helpful to think of a guideline as a criterion for the design of a method than to think of it as either a part or kind of that method.

certain actions, and the tools that mediate activity. Activity Theory provides an effective lens for analyzing tasks and settings and provides a framework for designing CLEs (Jonassen & Rohrer-Murphy,).1999

Another method for isolating required activity structures is cognitive task analysis using the PARI approach (Hall, Gott, & Pokorny, 1994). The PARI (precursor/action/result/interpretation) method uses pairs of experts to pose questions and think aloud while solving complex problems. It identifies not only the activities that are engaged in while solving a problem, but also the domain knowledge and strategic knowledge that enable solution of the problem. Activity structures can be evaluated within any community context for their relevance and importance to that community.

Authentic can also simply mean personally relevant or interesting to the learner. The *Jasper* series, for instance, provides engaging problems, conveyed in high-quality video, that middle school students identify with, even though most students have never experienced the kind of problem or context presented. Authentic problems, for purposes of designing CLEs, engage learners; they represent a meaningful challenge to them. See Petraglia (1998) for a fascinating discussion of authenticity in learning environments.

1.3. Problem Manipulation Space

A critical characteristic of meaningful learning is mindful activity. In order for learners to be active, they must manipulate something (construct a product, manipulate parameters, make decisions) and affect the environment in some way. Activity theory describes the transformational interactions among the learner, the object that the learner is acting on, and the signs and tools which mediate that interaction. The problem manipulation space provides the objects, signs, and tools* required for the learner to manipulate the environment. Why? Students cannot assume any ownership of the problem unless they know that they can affect the problem situation in some meaningful way.

The form of the problem manipulation space will depend on the nature of the activity structures the CLE is engaging.** However, it should provide a physical simulation of the real-world task environment, that is, a phenomenaria (Perkins, 1991). Phenomenaria, or microworlds, present a simplified model, along with observation and manipulation tools necessary for testing learners' hypotheses about their problems (Jonassen, 1996a). Learners are directly engaged by the world they explore, because they can experiment and immediately see the results of their experiment. If constructing a constitution, show the social, political, and military results of each of the articles included. Ethical judgments might be tested with briefs from real court cases. Stream models can be created to graphically illustrate the effects of contaminants and clean-up activities.

* Are these parts, kinds, or criteria for the problem manipulation space?
** Here is a clear indication of a situationality (see chap. 1, p. 8).

Problem manipulation spaces are causal models that enable students to test the effects of their manipulations, receiving feedback through changes in the appearance of the physical objects they are manipulating or in the representations of their actions, such as charts, graphs, and numerical output. They should be manipulable (allow learners to manipulate objects or activities), sensitive (ensure the environment responds in realistic ways to learner manipulations), realistic (have high fidelity of simulation), and informative (provide relevant feedback).* Later, I will describe dynamic modeling tools (a combination of problem manipulation space and cognitive modeling tools) that enable learners to construct and test their own models of task worlds.

In creating problem manipulation spaces, it is not always necessary for learners to manipulate physical objects or simulations of those objects. It may be sufficient merely to generate a hypothesis or intention to act and then to argue for it.** When engaging learners in solving ill-structured problems, requiring learners to articulate their solutions to problems and then to develop a coherent argument to support that solution is often sufficient (Jonassen, 1997). The argument is an excellent indicator of the quality of domain knowledge possessed by the learner. However, argumentation skills in most learners are underdeveloped, so it will be necessary to scaffold or coach the development of cogent arguments, perhaps using argument templates or checklists (described later under conversation tools).

2. Related Cases

Understanding any problem requires experiencing it and constructing mental models of it. What novice learners lack most are experiences. This lack is especially critical when trying to solve problems. So, it is important that CLEs provide access to a set of related experiences to which novice students can refer. The primary purpose of describing related cases is to assist learners in understanding the issues implicit in the problem representation. Related cases in CLEs support learning in at least two ways: by scaffolding student memory and by enhancing cognitive flexibility.***

Scaffold Student Memory: Case-Based Reasoning

The lessons that we understand the best are those in which we have been most involved and have invested the greatest amount of effort. Related cases can scaffold (or supplant) memory by providing representations of experiences that learners have not had. They cannot replace learners' involvement, but they can provide referents for comparison. When humans first encounter a situation or problem, they naturally first check their memories for similar cases that they may have solved previously (Polya, 1957). If they can recall a similar case, they try to map the previous

* Are these parts, kinds, or criteria for the problem manipulation space?
** This is an alternative kind of the method, manipulation space, and what follows is a general indication of the situation that calls for its use.
*** Are these parts, kinds, criteria, or something else (for the method, related cases)?

experience and its lessons onto the current problem. If the goals or conditions* match, they apply their previous case. By presenting related cases in learning environments, you are providing the learners with a set of experiences to compare to the current problem or issue.

Case-based reasoning argues that human knowledge is encoded as stories about experiences and events (Schank, 1990).** So, when people experience a problem or situation that they do not understand, they should be told stories about similar situations that function as lessons for the current problem. Learners retrieve from related cases advice on how to succeed, on pitfalls that may cause failure, and on what worked or didn't work and why (Kolodner, 1993). They adapt the explanation to fit the current problem.

In order to provide a rich set of related cases that will help learners to solve the current one, it is necessary to collect a set of cases that are representative of the current one (those with similar contexts, solutions, or results), identify the lessons that each can teach, characterize the situations in which each case can teach its lesson, and develop an index and represent its features in a way that allows cases to be recalled (Kolodner, 1993). If constructing a constitution, provide examples of constitutions from other emerging democracies, along with descriptions of social and political consequences (e.g., newspaper or magazine clippings, video footage). In a case-based learning environment in transfusion medicine, we provided a set of related cases that could be accessed by medical students who were involved in solving new cases in transfusion medicine (Jonassen, Ambruso, & Olesen, 1992). Case reviews were indexed to each of the practice cases based on the similarities in symptomatology, pathophysiology, and so on. Learners were provided the opportunity in every case to review related cases. Developing a story index, representing those stories, and providing access to them at appropriate times is difficult but very effective.

Another way of scaffolding (or supplanting) memory for novices is to provide worked examples of problems (described later).

Enhance Cognitive Flexibility

Related cases also help to represent complexity in CLEs by providing multiple perspectives, themes, or interpretations on the problems or issues being examined by the learners. Instruction often filters out the complexity that exists in most applied knowledge domains, causing shallow understanding of domain knowledge to develop.

An important model for designing related cases in CLEs, cognitive flexibility theory, provides multiple representations of content in order to convey the complexity that is inherent in the knowledge domain (Jonassen, 1993; Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987). Stress the conceptual interrelatedness of ideas and their interconnectedness by providing multiple interpretations of content. Use multiple, related cases to convey the multiple perspectives on most problems. To enhance cognitive flexibility, it is important that related cases provide a variety of viewpoints and perspectives on the case or project being solved. For instance, if resolving ethical dilemmas, provide divergent personal interpretations of the dilemma as well as interpretations of similar ethical conundrums, in order to convey thematic perspectives. By contrasting the cases, learners construct their own interpretations.

* These are situationalities, but for the task (content) rather than for the instructional theory (method).

** See also chapter 8 by Schank, Berman, and Macpherson.

3. Information Resources

In order to investigate problems, learners need information with which to construct their mental models and formulate hypotheses that drive the manipulation of the problem space. So, when designing CLEs, you should determine what kinds of information the learner will need in order to understand the problem. Rich sources of information are an essential part of CLEs. CLEs should provide learner-selectable information just-in-time. CLEs assume that information makes the most sense in the context of a problem or application. So, determine what information learners need in order to interpret the problem. Some of it is naturally included in the problem representation. Other relevant information banks and repositories should be linked to the environment. These may include text documents, graphics, sound resources, video, and animations that are appropriate for helping learners comprehend the problem and its principles.

The World Wide Web is the default storage medium, as powerful new plug-ins enable users to access multimedia resources from the net. Too many learning environments, however, embed hypertext links to Web sites based on the surface features of the site. Since learners do not possess sophisticated literacy skills for evaluating the quality of and filtering the information provided, information resources included in or linked to a CLE should be evaluated for their relevance and organized for ready access in ways that support the kind of thinking that you want the learners to do. Based on the activity structures that support the problem solution, information needed to perform each of the tasks should be linked to those activities. With learners who are new to CLEs, simply pointing to Web resources may provide serious distractions to thinking necessary for solving the problem.

4. Cognitive (Knowledge-Construction) Tools

If CLEs present complex, novel, and authentic tasks, you will need to support learners' performance of those tasks. To do that, you must identify the activity structures that are required to solve the problem. Which of the required skills are likely to be possessed by the learners? For those that are not, you should provide cognitive tools that scaffold the learners' abilities to perform those tasks.

Cognitive tools are generalizable computer tools that are intended to engage and facilitate specific kinds of cognitive processing (Kommers, Jonassen, & Mayes, 1992). They are intellectual devices that are used to visualize (represent), organize, automate, or supplant thinking skills. Some cognitive tools replace thinking, while others engage learners in generative processing of information that would not occur without the tool.*

Cognitive tools fulfill a number of intellectual functions in helping learners interact with CLEs. They may help the learners to better represent the problem or task they are performing (e.g., visualization tools). They may help the learners to represent what they know or what they are learning (static and dynamic knowledge modeling tools), or they may offload some of the cognitive activity by automating low-level tasks or supplanting some tasks (performance support). Finally, cognitive tools may help learners to gather important information needed to solve the problem. Each kind of cognitive tool engages or replaces different cognitive activity, so cognitive tools must be selected carefully to support the kind of processing that needs to be performed.

Problem/Task Representation Tools

Learners' mental models of objects, systems, or other phenomena possess visual-spatial components (Jonassen & Henning, 1996). In order to understand a phenomenon, it is necessary for most humans to generate a mental image of it. Visualization tools help learners to construct those mental images and visualize activities. For example, graphical user interfaces visually represent files and applications to be manipulated.

Numerous visualization tools provide reasoning-congruent representations that enable learners to reason about objects that behave and interact (Merrill, Reiser, Bekkalaar, & Hamid, 1992). Examples include the graphical proof tree representation in the Geometry Tutor (Anderson, Boyle, & Yost, 1986); the Weather Visualizer (colorizes climatological patterns); and the Climate Watcher (colorizes climatological variables; (Edelson, Pea, & Gomez 1996). Programs such as MATHEMATICA and MATHLAB are often used to visually represent mathematical relationships in problems so that learners can *see* the effects of any problem manipulation.

Visualization tools tend to be task- and domain-specific. There are no general-purpose visualization tools. Rather, these tools must closely mimic the nature of images required to understand the ideas. As a CLE designer, you should analyze the activity structures required to solve the problems and identify processes that need to be represented visually and how the learner needs to manipulate those images to test their models of the phenomena.

* Are these parts, kinds, or criteria for cognitive tools?

4.2. Static and Dynamic Knowledge Modeling Tools

Jonassen (1996a) describes the critical thinking and knowledge representation activities involved in articulating knowledge domains using different static knowledge representation tools, such as databases, spreadsheets, semantic networks, expert systems, and hypermedia construction. As students study phenomena, it is important that they articulate their understanding of the phenomena. Modeling tools provide knowledge representation formalisms that constrain the ways learners think about, analyze, and organize phenomena, and they provide an environment for encoding their understanding of those phenomena. For example, creating a knowledge database or a semantic network requires learners to articulate the range of semantic relationships among the concepts that comprise the knowledge domain. Expert systems engage learners in articulating the causal reasoning between objects or factors that predict outcomes in a domain. Modeling tools help learners to answer "what do I know?" and "what does it mean?" questions.* As a CLE designer, you must decide when learners need to articulate what they know and which formalism will best support their understanding.

Complex systems contain interactive and interdependent components. In order to represent the dynamic relationships in a system, learners can use dynamic modeling tools for building simulations of those systems and processes and for testing them. Programs like Stella and PowerSim use a simple set of building blocks to construct a map of a process. Learners supply equations that represent causal, contingent, and variable relationships among the variables identified on the map. Having modeled the system, simulation modeling tools enable learners to test the model and observe the output of the system in graphs, tables, or animations. At the run level, students can change the variable values to test the effects of parts of a system on the others.

Building models of real-world phenomena is at the heart of scientific thinking and requires diverse mental activities such as planning, data collecting, accessing information, data visualizing, modeling, and reporting (Soloway, Krajcik, & Finkel, 1995). The process for developing the ability to model phenomena requires defining the model, using the model to understand some phenomena, creating a model by representing real-world phenomena and making connections among its parts, and finally analyzing the model for its ability to represent the world (Spitulnik, Studer, Finkel, Gustafson, & Soloway, 1995). They have developed a user-friendly dynamic modeling tool (Model-It) which scaffolds the use of mathematics by providing a range of qualitative relationships that describe the quantitative relationships among the factors or by allowing them to enter a table of values

* Is a modeling tool an instructional method? If not, what relationship does it have to an instructional method, and what is that method? What about performance support tools and information gathering tools (see next two subsections)?

that they have collected. Young learners create and then test models that represent real-world phenomena.

Performance Support Tools

In many environments, performing repetitive, algorithmic tasks can rob cognitive resources from more intensive, higher order cognitive tasks that need to be performed. Therefore, CLEs should automate algorithmic tasks in order to offload the cognitive responsibility for their performance. For example, in business problem-solving environments, we have provided spreadsheet templates of problems for learners to test their hypotheses about levels of production, inventory, and sales. Most forms of testing in CLEs should be automated so that learners can simply call for test results. Generic tools such as calculators or database shells may be embedded to help learners organize the information they collect. Most CLEs provide notetaking facilities to offload memorization tasks. Identify in the activity structures those tasks that are facile for learners and those that may distract reasoning processes, and try to find a tool which supports that performance.

Information Gathering Tools

As stated before, information resources are important to understanding phenomena. Library research has shown that most learners are not skilled information seekers. The process of seeking information may distract learners from their primary goal of problem solving. So, embedding search tools may facilitate learning. Sophisticated search engines (many with graphical interfaces) and intelligent agents are in common use for seeking out and filtering information sources on the Web and selecting information that may be relevant to the user. Consider embedding information gathering tools like these in CLEs.

5. Conversation and Collaboration Tools

Contemporary conceptions of technology-supported learning environments assume the use of a variety of computer-mediated communications to support collaboration among communities of learners (Scardamalia, Bereiter, & Lamon, 1994). Why? Learning most naturally occurs not in isolation but by teams of people working together to solve problems. CLEs should provide access to shared information and shared knowledge-building tools to help learners to collaboratively construct socially shared knowledge. Problems are solved when a group works toward developing a common conception of the problem, so their energies can be focused on solving it. Conversations may be supported by discourse communities, knowledge-building communities, and communities of learners.

People who share common interests enjoy discussing their interests. In order to expand the community of discussants, people talk with each other through newsletters, magazines, and television shows. Recently, computer networks have evolved

to support discourse *communities* through different forms of computer conferences (listservs, electronic mail, bulletin boards, NetNews services, chats, MUDs (multiuser dimensions) and MOOs (MUDs object oriented). These technologies support discourse on a wide range of topics.

Scardamalia and Bereiter (1996) argue that schools inhibit, rather than support, knowledge building by focusing on individual student abilities and learning. In *knowledge-building communities*, the goal is to support students to "actively and strategically pursue learning as a goal" (Scardamalia et al., 1994, p. 201).* To enable students to focus on knowledge construction as a primary goal, Computer-Supported Intentional Learning Environments (CSILEs) help students to produce knowledge databases so that their knowledge can "be objectified, represented in an overt form so that it could be evaluated, examined for gaps and inadequacies, added to, revised, and reformulated" (p. 201). CSILEs provide a medium for storing, organizing, and reformulating the ideas that are contributed by each of the members of the community. The knowledge base represents the synthesis of their thinking, something they own and of which they can be proud.

CLEs can also foster and support *communities of learners* (COLs). COLs are social organizations of learners who share knowledge, values, and goals (see, e.g., Bielaczyc & Collins, chap. 12 of this volume). COLs emerge when students share knowledge about common learning interests. Newcomers adopt the discourse structure, values, goals, and beliefs of the community (Brown, 1994). COLs can be fostered by having the participants conduct research (reading, studying, viewing, consulting experts) and share information in the pursuit of a meaningful, consequential task (Brown & Campione, 1996). Many of these learning community environments support reflection on the knowledge constructed and the processes used to construct it by the learners.** Scaffolded environments that support COLs include the Collaboratory Notebook (Edelson, Pea, & Gomez, 1996); CaMILE (Guzdial, Turns, Rappin, & Carlson, 1995), and the Knowledge Integration Environment (Bell, Davis, & Linn, 1995). Their common belief is that learning revolves around learners' conversations about what they are learning, not teacher interpretations.

In order to support collaboration within a group of learners, who may be either co-located or at a distance, CLEs should provide for and encourage conversations about the problems and projects the students are working on. Students write notes to the teacher and to each other about questions, topics, or problems that arise. Textualizing discourse among students makes their ideas appear to be as important as each other's and the instructor's comments (Slatin, 1992). When learners collaborate, they share the same goal: to solve the problem or reach some scientific consensus about an issue.

CLEs should support collaboration within a group of participants, shared decision making about how to manipulate the environment, alternative interpretations of top-

* See also chapter 12 by Bielaczyc and Collins.
** Reflection is a common feature in many theories in the new paradigm.

ics and problems, articulation of learners' ideas, and reflection on the processes they used.* Collaboration on solving a problem requires shared decision making, which proceeds through consensus-building activities to socially shared construction of knowledge and understanding about the problem. Reflection through computer conferences also engenders metaknowledge, the knowledge that participants have of the process in which the class is operating as well as the knowledge of themselves as participants in an evolving, ongoing conversation (Slatin, 1992).

6. Social/Contextual Support

Throughout the history of instructional design and technology, projects have failed most often because of poor implementation. Why? Because the designers or technology innovators failed to accommodate environmental and contextual factors affecting implementation. Frequently they tried to implement their innovation without considering important physical, organizational, and cultural aspects of the environment in which the innovation was being implemented.** For instance, many implementations of film and video failed because the physical environment couldn't be darkened sufficiently, adequate equipment wasn't available, or the content of the film or video was inimical or culturally insensitive to the audience. So the message was rejected by the learners.

In designing and implementing CLEs, accommodating contextual factors is important to successful implementation. It is also necessary to train the teachers and personnel who will be supporting the learning and to train the students who will be learning from the environments. The CoVis project (Edelson et al., 1996) supports teachers by sponsoring workshops and conferences in which teachers can seek help from and establish a consensus with the researchers. Questions can be posed by teachers, which are answered by peer teachers or technical staff. Social and contextual support of teachers and users is essential to successful implementation of CLEs.

SUPPORTING LEARNING IN CLEs

Table 10.1 lists learning activities that students perform in CLEs and instructional activities the CLE provides to support them. In most CLEs, learners need to explore; articulate what they know and have learned; speculate (conjecture, hypothesize, test); manipulate the environment in order to construct and test their theories and models; and reflect on what they did, why it did or didn't work, and what they have learned from the activities.

* Are these parts, kinds, or criteria?

** This highlights the importance of systemic thinking for recognizing and dealing with interdependencies between an instructional system and its environment, for the successful implementation of a new paradigm of instruction. See, e.g., the chapter by Reigeluth (1995) in G. Anglin (Ed.), *Instructional Technology: Past, Present, and Future (2nd Ed.).* Englewood, CO: Libraries Unlimited. Perkins and Unger (chap. 5) also raised this concern.

Learning Activities	*Instructional Activities*
Exploration	Modeling
Articulation	Coaching
Reflection	Scaffolding

Exploring attributes of the problem includes investigating related cases for similarities, and perusing information resources to find evidence to support solution of the problem or completion of the project that focuses the CLE. The most important cognitive components of exploration are goal-setting and managing the pursuit of those goals (Collins, 1991). What are the cognitive entailments of exploration?

The cognitive activities engaged while exploring CLEs include speculating and conjecturing about effects, manipulating the environment, observing and gathering evidence, and drawing conclusions about those effects. Most of these activities require reflection-in-action (Schon, 1982). Skilled practitioners often articulate their thoughts while performing, that is, they reflect-in-action.

CLEs also require articulating and reflecting on one's learning performance. Reflecting-on-action—standing outside yourself and analyzing your performance—is essential to learning. Requiring learners to articulate what they are doing in the environment and the reasons for their actions and to explain the strategies they use supports knowledge construction and metacognition.* Collins and Brown (1988) when learners imitate and practice the performance that is modeled for them, and the teachers replays learners' performances (using videotape, audit trails, think alouds, etc.), for they engage learners in reflection-on-action.

These learning activities indicate the goals for providing instructional supports in CLEs, such as modeling, coaching, and scaffolding (illustrated in Fig. 10.1).

A. Modeling

Modeling is the easiest implemented instructional strategy in CLEs. Two types of modeling exist: behavioral modeling of the overt performance and cognitive modeling of the covert cognitive processes. Behavioral modeling in CLEs demonstrates how to perform the activities identified in the activity structure. Cognitive modeling articulates the reasoning (reflection-in-action) that learners should use while engaged in the activities.

Model Performance

Carefully demonstrate each of the activities involved in a performance by a skilled (but not an expert) performer. When learners need help in a CLE, they might press a "Show Me" or a "How Do I Do This?" button. Modeling provides learners with an example of the desired performance. It is important to point out each of the discrete

* Such higher-order thinking skills are an important kind of learning (goal) that received little attention in the industrial-age paradigm of instruction.

actions and decisions involved in the performance, so that the learner is not required to infer missing steps. A widely recognized method for modeling problem solving is worked examples.

Worked examples include a description of how problems are solved by an experienced problem solver (Sweller & Cooper, 1985). Worked examples enhance the development of problem schemas and the recognition of different types of problems based on them. Using worked examples redirects the learner's attention away from the problem solution and toward problem-state configurations and their associated moves. Worked examples should be augmented by articulation of the reasoning (reflection-in-action) by the performer.

Articulate Reasoning

As an experienced performer models problem-solving or project skills, he or she should also articulate the reasoning and decision making involved in each step of the process, that is, model the covert as well as the overt performance. For example, record the performer thinking aloud while performing. Analyze the protocol in order to provide cues to the learners about important actions and processes, perhaps even elaborating on, or providing alternative representations of, those activities. You might also record the performer conducting a postmortem analysis or abstracted replays, where you discuss the performer's actions and decisions.

In solving the ill-structured problems that characterize most CLEs, learners need to know how to develop arguments to support their solutions to the problem. In these cases, performers should overtly model the kinds of argumentation necessary to solve the problem. You might also consider providing reasoning-congruent visual representations (described before) generated by the skilled performer. These visual models of the objects of expert reasoning may provide rich alternative representations to help learners perceive the structure of reasoning. You might also have performers use some of the cognitive tools to represent their understanding of, or reasoning through of the problem. The purpose in all of these is to make the covert overt, so that it can be analyzed and understood and so that learners know why they should perform, as well as how to perform.

B. Coaching

Modeling strategies focus on how expert performers function. The assumption of most instruction is that, in order to learn, learners will attempt to perform like the model, first through crude imitation, advancing through articulating and habituating performance, to the creation of skilled, original performances. At each of these stages, learners' performances will likely improve with coaching. The role of coach is complex and inexact. A good coach motivates learners, analyzes their performances, provides feedback and advice on the performances and how to learn about how to perform, and provokes reflection on and articulation of what was learned.

Coaching may be solicited by the learner. Students seeking help might press a "How Am I Doing?" button. Or coaching may be unsolicited, when the coach observes the performance and provides encouragement, diagnosis, directions, and feedback. Coaching naturally and necessarily involves responses that are situated in the learner's task performance (Laffey, Tupper, Musser, & Wedman, 1997). You can include the following kinds of coaching in CLEs.

Provide Motivational Prompts

A good coach relates the importance of the learning task to the learner. In case the learners are not immediately engaged by the problem, then the CLE coach needs to provide learners a good reason for becoming engaged. Once started, the coach should boost the learners' confidence levels, especially during the early stages of the problem or project. Motivational prompts can usually be faded quickly once learners become engaged by the problem. It may be necessary to provide additional, intermittent prompts during the performance of particularly difficult tasks.

Monitor and Regulate the Learner's Performance

The most important role of the coach is to monitor, analyze, and regulate the learners' development of important skills. Coaching may:

- provide *hints* and *helps*, such as directing learners to particular aspects of the tasks or reminding learners of parts of the task they may have overlooked;
- prompt appropriate kinds of thinking, such as suggestions to generate images, make inferences, generalize another idea, use an analogy, make up a story, generate questions, summarize results, or draw an implication;
- prompt the use of collaborative activities;
- prompt consideration of related cases or particular information resources that may help learners interpret or understand ideas;
- prompt the use of specific cognitive tools that may assist articulation and understanding of underlying concepts or their interrelationships;
- provide feedback that not only informs the learners about the effectiveness and accuracy of their performance, but also analyzes their actions and thinking.

Provoke Reflection

A good coach becomes the conscience of the learner. So, a good coach provokes learners to reflect on (monitor and analyze) their performance. Engaging the monitoring of comprehension and the selection of appropriate cognitive strategies can be implemented in CLEs by inserting provoking questions that:

- ask the learners to reflect on what they have done,
- ask the learners to reflect on what assumptions they made,
- ask the learners to reflect on what strategies they used,

- ask the learners to explain why they made a particular response or tool an action,
- ask learners to confirm an intended response,
- ask learners to state how certain they are in a response,
- require learners to argue with the coach,
- provide puzzles that learners need to solve which will lead to appropriate performance.

Perturb Learners' Models

The mental models that naive learners build to represent problems are often flawed. They often misattribute components of the problem or incorrectly connect them, so they are trying to solve the wrong kind of problem. So it is necessary to perturb the learner's model.* When learners see that their models do not adequately explain the environment they are trying to manipulate, they adjust or adapt the model to explain the discrepancies.

Perturbing learners' understanding can be accomplished by embedding provoking questions (Have you thought about ... ?, What will happen if ... ?, Does your model explain ... ?). It is also useful to require learners to reflect on actions they have taken (Why did you ... ?, What results did you expect ... ?, What would have happened if ... ?). A simpler approach is to ask learners to confirm or clarify what did happen (Why did that reaction occur ... ?). Along with eliciting responses, the coach should ascertain the learner's response certainty. That is, when a learner makes a response (keys a response into the computer), a simple probe (On a scale of 1 to 10, how sure are you of that response?) will cause the learner to reflect on how much he or she knows about the subject. This tactic will likely not work for every response due to learner fatigue, so reserve it for the important interactions. Another approach to perturbing learner models is to provide dissonant views or interpretations in response to student actions or interpretations.

Most of the coaching processes, especially the monitoring and regulation of learner performance, require some form of intelligence in the CLE system in order to judge the performance. That normally entails some form of expert model of the performance and thinking to be used as the benchmark for analyzing and comparing the student's performance, thinking, and resulting mental model.

C. Scaffolding

Modeling is focused on the expert's performance. Coaching is focused on the learner's performance. Scaffolding is a more systemic approach to supporting the learner, focusing on the task, the environment, the teacher, and the learner. Scaffolding provides temporary frameworks to support learning and student performance beyond the learners' capacities.

The concept of scaffolding represents any kind of support for cognitive activity that is provided by an adult when the child and adult are performing the task together (Wood & Middleton, 1975). Wood, Bruner, and Ross (1976) describe scaffolding during problem solving as recruiting the child's interest, simplifying the task, motivating the child, and demonstrating the correct performance. Resnick (1988) proposes that record keeping and other tools, especially representational devices commonly found in computer microworlds, can serve as instructional scaffolds. Lehrer (1993) also suggests scaffolding with computer tools, as well as scaffolding through alternative assessments. It is obvious from these descriptions that the concept of scaffolding is fuzzy and indistinct as it relates to modeling and coaching.

For purposes of CLEs, I believe that scaffolding represents some manipulation of the task itself by the system. When scaffolding performance, the system performs part of the task for the student, supplants the student's ability to perform some part of the task by changing the nature of the task or imposing the use of cognitive tools that help the learner perform, or adjusts the nature or difficulty of the task. Whereas coaching focuses on an individual task performance, scaffolding focuses on the inherent nature of the task being performed. A learner's request for scaffolding might take the form of a "Help Me Do This" button.

Learners experiencing difficulties in performing a task possess insufficient prior knowledge or readiness to perform. This suggests three separate approaches to scaffolding of learning: adjust the difficulty of the task to accommodate the learner, restructure the task to supplant a lack of prior knowledge, or provide alternative assessments. Designing scaffolds requires explication of the activity structure required to complete a job (using activity theory or cognitive task analysis, as described before). From the list of tasks or activities, identify those that are not currently possessed by the learners or for which the learners are not ready (defining the learner's zone of proximal development).

Adjust Task Difficulty

Scaffolding may provide an easier task. Start the learners with the tasks they know how to perform and gradually add task difficulty until they are unable to perform alone. This will be their zone of proximal development. This form of task regulation is an example of black-box scaffolding (Hmelo & Guzdial, 1996), that which facilitates student performance but which will not be faded out while learners are using the environment. This is the kind of scaffolding that learners cannot see; the adult supporter is invisible.

Restructure a Task to Supplant Knowledge

Another approach to scaffolding learners' performance is to redesign the task in a way that supports learning, that is, supplanting task performance (Salomon, 1979).

* The development of learners' mental models is a kind of learning that was not often addressed in the industrial-age paradigm, but is a common feature of most theories in the new paradigm (see chap. 3, p. 54, "Understand relationships").

Task performance may also be supplanted by suggesting or imposing the use of cognitive tools to help learners represent or manipulate the problem. These forms of scaffolding are examples of glass-box scaffolding (Hmelo & Guzdial, 1996) because they are faded after a number of cases. Otherwise they become intellectual crutches. Learners need to be helped to perform that which they cannot do alone. Having performed desired skills, they must learn to perform without the scaffolds that support their performance.

Provide Alternative Assessments

Learning is, to a large degree, assessment-driven. Learners develop fairly sophisticated strategies for identifying the expected performance and studying accordingly. More often than not, that performance is reproductive, so learners develop strategies for identifying what the teacher will believe is important and memorizing that. Test pools and notetaking services scaffold this kind of learning. However, when learners apply these reproductive strategies in problem-oriented CLEs, they often fail.* Learners must be aware of the complex nature of the learning task and understand what the task means, so that they metacognitively adjust their attention, effort, and thinking strategies to accommodate the task. In CLEs, it is important that the project or problem requirements are clearly communicated, so that learners understand what will be required of them. This may be done through worked examples of sample problems or sample questions, as well as understanding the nature of the problem. The problem representation and decomposition process cannot begin until learners understand what the solution will be like (Jonassen, 1997).

CONCLUSION

This chapter has cursorily described a model for designing CLEs. It has conceptually described the components of a CLE and the strategies for supporting learners' performances in them. Because of page limitations, I was unable to articulate the philosophical assumptions behind CLEs, impediments to learning from CLEs, how to evaluate learning in CLEs, and alternative approaches to using technology to support constructive learning. Those topics will be addressed in other publications.

It is important to note that this model is intended to provide guidelines for designing learning environments to support constructive learning. Constructive learning emphasizes personal meaning making and so intentionally seeks to relate new ideas to experiences and prior learning. Constructive learning therefore engages conceptual and strategic thinking, in contrast to reproductive learning. CLEs are not appropriate for all learning outcomes. If you want to design learning environments to engage learners in personal and/or collaborative knowledge construction and problem solving outcomes, then consider designing CLEs.

* This helps identify ways that the new paradigm differs from the industrial-age paradigm of instruction.

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