University of Colorado at Boulder

Gerhard Fischer
Department of Computer Science

ECOT 7-7 Engineering Center
Campus Box 430
Boulder, Colorado 80309-0430
(303) 492-1502, FAX: (303) 492-2844
e-mail: gerhard@boulder.colorado.edu

Supporting Learning on Demand
with Design Environments

Gerhard Fischer
Department of Computer Science and Institute of Cognitive Science
Campus Box 430, University of Colorado at Boulder
Boulder, CO 80303

Abstract. Information overload, high functionality systems, and the rapid change of our world have created new problems and new challenges for education and training. New instructional approaches are needed to circumvent the unsolvable problems of *coverage* and *obsolescence*.

Learning on demand is a promising approach for addressing these problems because: (1) It contextualizes learning by allowing it to be integrated into work rather than relegating it to a separate phase, (2) it lets learners see for themselves the usefulness of new knowledge for actual problem situations, thereby increasing the motivation for learning new things, and (3) it makes new information relevant to the task at hand, thereby leading to more informed decision making, better products, and improved performance.

We have developed a *conceptual framework* (including the support of situated cognition, and the integration of action and reflection), a *system architecture* (integrating domain-oriented construction kits, hypermedia systems, and case-based libraries), and *prototype systems* (e.g., for architectural design, for software design, etc.) in support of learning on demand.

Supporting Learning on Demand
with Design Environments

Gerhard Fischer
Department of Computer Science and Institute of Cognitive Science
Campus Box 430, University of Colorado at Boulder
Boulder, CO 80303

Abstract. Information overload, high functionality systems, and the rapid change of our world have created new problems and new challenges for education and training. New instructional approaches are needed to circumvent the unsolvable problems of *coverage* and *obsolescence*.

Learning on demand is a promising approach for addressing these problems because: (1) It contextualizes learning by allowing it to be integrated into work rather than relegating it to a separate phase, (2) it lets learners see for themselves the usefulness of new knowledge for actual problem situations, thereby increasing the motivation for learning new things, and (3) it makes new information relevant to the task at hand, thereby leading to more informed decision making, better products, and improved performance.

We have developed a *conceptual framework* (including the support of situated cognition, and the integration of action and reflection), a *system architecture* (integrating domain-oriented construction kits, hypermedia systems, and case-based libraries), and *prototype systems* (e.g., for architectural design, for software design, etc.) in support of learning on demand.

1 Learning on Demand — Why

The major justification for learning on demand is based on the necessity for education to be regarded as a distributed lifelong process; a process of learning new material as it is needed, which is even more pronounced once formal education is completed and practical work situations are encountered. Success models of learning on demand have existed in human societies in situations where a learner could afford the luxury of a personal coach and critic. By having a human coach or critic, learners can obtain support for *their* problem solving activities.

Coverage and Obsolescence. Technologically oriented design fields are growing and changing at an alarming rate. Learning everything in advance (e.g., in high functionality systems [Draper 84]) is impossible because there are too many things to learn. The rapidly changing nature of available design objects (especially in all fields related to information technology) poses the problem that our knowledge needs to be updated constantly. The large and growing discrepancy between the amount of potentially relevant knowledge and the amount users can know and remember makes support for learning on demand one of the most important activities.

New Cognitive Science Approaches Toward Learning and Training. Current cognitive theory [Resnick 89] emphasizes that learning is a process of knowledge construction, not one of knowledge recording or absorption [Papert 86]. Successful learners elaborate and develop self-explanations that extend the information in texts or other instructional materials. Learning is knowledge dependent; people use current knowledge to construct new knowledge and to restructure existing knowledge [Kintsch 88]. Learning is highly tuned to the situation in which it takes place [Greeno 89; Lave 88; Suchman 87; Winograd, Flores 86]. No amount of knowledge of principles suffices to account for or guarantee the success of action in real-world problem situations. This challenges many of the basic assumptions about learning general problem-solving skills in a decontextualized way. Contextual elaboration is needed to devise specific courses of action in order to go beyond general procedural prescriptions. Learning on demand is a promising approach for addressing these challenges.

Integrating Action and Reflection. The work process of many practitioners can be described by a *reflection-in-action* model [Schoen 83]. Action is governed by a nonreflective thought process and proceeds until it breaks down. A breakdown occurs when the practitioner realizes that nonreflective action has resulted in unanticipated consequences—either good or bad. In order to notice the breakdown, the "situation has to talk back" to the practitioner. Reflection is used to repair the breakdown, and then (nonreflective) situated action continues. Reflection-in-action takes place within the *action present*, i.e., the time period during which the decision to act has been made but the final decision about how to act has not. Mechanisms in support of learning on demand are required to take advantage of breakdown situations.

2 Learning on Demand — How

Our early work in support of learning on demand focused on two types of systems: active help systems and critiquing systems. *Active help systems* [Fischer, Lemke, Schwab 85] volunteer information. They address the problem that demands cannot originate from users in situations where users are unaware that additional relevant functionality to their task at hand exists in the system. The system itself has to take the initiative. One of the major problems with these type of systems is to avoid having them become too intrusive. *Critiquing systems* [Fischer et al. 90] present a reasoned opinion about a user's product or action. Critics use knowledge of design principles to detect and critique suboptimal solutions constructed by designers and increase the "back-talk" of the situation.

Design Environments. Design environments are *domain-oriented* to support human problem-domain communication [Fischer, Lemke 88], and with the help of critics they *integrate* knowledge-based graphic construction kits (in support of action) with hypermedia systems (in support of reflection) [Fischer, McCall, Morch 89]. Design environments enable designers *to learn within the context of their work on real-world problems* [Fischer, Lemke, McCall 90]. With such systems, learning does not take place in a separate phase and in a separate place but is integrated with working and contextualized by situations. The systems let users construct solutions to design problems, advise them when they are getting into trouble, and then provide directly relevant information. A basic assumption behind them is that by letting users see for themselves the usefulness of new knowledge for actual problem situations, the *motivation* of users will be increased for learning new things.

JANUS [Fischer, McCall, Morch 89] is a design environment that supports architectural design, specifically floor plan layout for kitchen design. JANUS consists of two subsystems: JANUS-CONSTRUCTION, a knowledge-based construction component, and JANUS-ARGUMENTATION, a hypermedia argumentation component. The critics [Fischer et al. 90] in JANUS-CONSTRUCTION are capable of evaluating design decisions (as expressed in the construction situation) and providing feedback when design principles are violated. The system not only provides the primitive elements of the design domain but also has an understanding of principles of good design in that domain. JANUS supports the construction of an artifact either "from scratch," by combining the primitives from a palette, or by modifying an already constructed artifact from its catalog.

The knowledge-based critiquing mechanism in JANUS bridges the gap between construction and argumentation. The critics provide the designer with immediate entry into the exact place in the hypermedia network where the argumentation relevant to the current construction task lies. The system supports learning on demand by providing argumentative information for construction effectively, efficiently, and without requiring the designers to (1) realize they need information, (2) suspect that needed information is in the system, or (3) know how to retrieve it.

An Architecture for Systems in Support of Learning on Demand. Based on our work on JANUS and a

number of other design environment building efforts [Lemke, Fischer 90; Dews 89], we have developed a multifaceted architecture in support of learning on demand (see Figure 1).
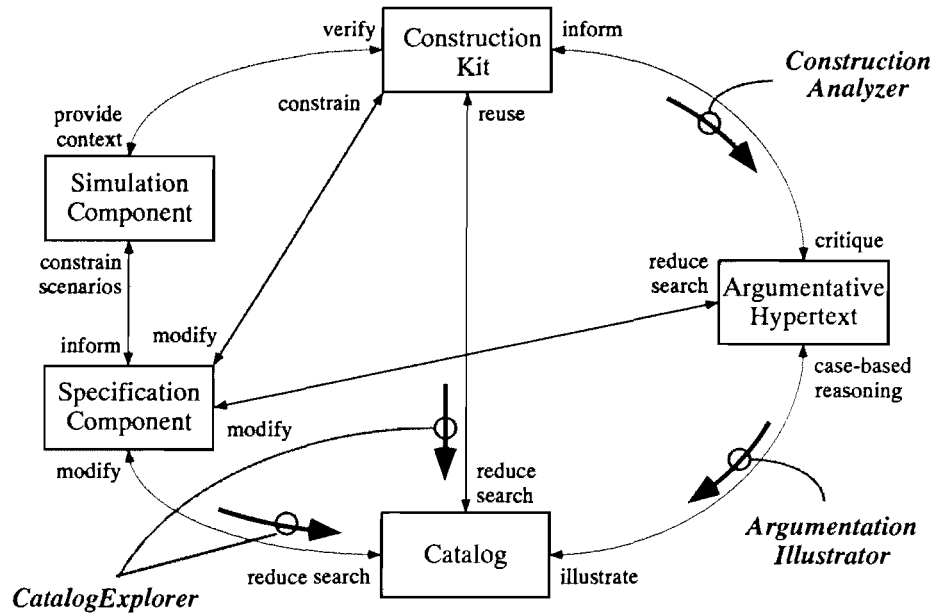

Figure 1: A Multifaceted Architecture in Support of Learning on Demand

In addition to the components already mentioned, the architecture contains a *specification component* allowing designers to articulate partial specifications, and a *simulation component* supporting users by allowing them to engage in usage scenarios with the artifact being designed. In order to support learning on demand, the architecture is integrated by the following components: CONSTRUCTION ANALYZER, CATALOG EXPLORER and ARGUMENTATION ILLUSTRATOR.

A prerequisite of learning on demand is that the demand must be noticed by the learner; therefore, it is necessary for the *situation to talk back*. However, for learners who do not have extensive experience in the domain, the situation is often mute unless the learning environment has a component that speaks up and points out issues that the designer may otherwise not have considered. The *CONSTRUCTION ANALYZER* fulfills this role by operating as a critiquing system. The critiquing approach *empowers users* by supporting learning on demand. Users increase their knowledge and their independence by working with systems that do not do the work for them, but make the arrangements necessary for them to do it themselves.

The *CATALOG EXPLORER* [Fischer, Nakakoji 91] links the specification and the construction with the catalog. By exploiting information contained in a partial specification and a partial construction, the system presents the examples in the catalog with respect to their relevance to the task at hand as articulated by the partial specification and construction.

The *ARGUMENTATION ILLUSTRATOR* is used to contextualize an argumentative principle in relation to a specific design. It provides a link back from argumentation to construction by making abstract principles concrete and ready to be integrated into the artifact under construction. Catalog examples support *case-based reasoning* [Riesbeck, Schank 89], which complements generalized argumentative reasoning when principles are not sufficiently well defined. To support these learning processes, catalog examples

must be annotated with design rationale that allow designers to assess the relevance of the example to the situation at hand. In addition to positive examples, the catalog also contains negative learning examples that show what design choices should be avoided and that assist learners in recognizing suboptimal designs.

3 Learning on Demand — Possibilities, Limitations, and Challenges

Beyond Tutoring and Open Learning Environments. The strength of tutoring systems [Wenger 87] lies in their ability to teach basic concepts and skills of a problem domain. However, they cannot be designed with the concrete problem-solving situation of users in mind. Problems presented by tutoring systems are *prespecified* by the system, and therefore are not suited to support learning on demand.

Unlike tutoring systems, open learning environments [Papert 80] do not suffer from the problem that presentation of instructional material is system controlled without regard to the learner's situation. But these environments have other shortcomings. Even the best environments do not cause or guarantee learning. In open learning environments, learners get trapped on suboptimal plateaus because they fail to discover the knowledge needed for better design, and there are no resources available to help learners detect mistakes or assist them when they get stuck.

Hypermedia Systems. Hypermedia is a promising new technology [Halasz 88; Sculley 89; Weyer 87] to be integrated into working and learning environments—but isolated hypermedia systems suffer from problems similar to those of open learning environments. The initial euphoria about hypermedia has been dampened by the realization that, unless carefully designed, hypermedia systems can fall short of realizing their potential [Fischer et al. 88; Akscyn, McCracken, Yoder 88]. Finding information that is not directly linked to the current browsing position is difficult. Learners are often unfamiliar with the structuring principles of the information space and so have additional problems navigating to the desired piece of information. The richness of information may cause learners to get sidetracked, forget their original goals, study irrelevant information, and, as a result, "get lost in hyperspace." The integration of hypermedia systems into design environments eliminates some of these problems and makes complex information spaces accessible with a demand generated by the doing of a user.

Motivation. Users are willing and motivated to learn when the following conditions hold: (1) learning is actively desired by and controlled by them, (2) new information is easy to find they are successful in finding and using it, (3) users can see the immediate benefit of learning something new to their current working situation, and (4) their environments are intrinsically motivating allow users to achieve favorable results with a reasonably small amount of effort. The pain and the cost of acquiring new tools must be far less than the pain and the cost of trying to master difficult problems with inadequate tools. There is overwhelming evidence that self-directed [Brown, Palincsar 89] and intentional learning [Bereiter, Scardamalia 89] are some of the most important aspects of successful learning experiences.

Challenges for Psychology. Learning on demand raises many *psychological questions*. Our prototype design environments allow us to explore the following questions: (1) how does learning on demand compare with other, conventional forms of learning? (2) how can we characterize the class of users (e.g., novices, intermediates, experts) that benefit most from using an integrated design environment? (3) will designers with limited expertise understand the critics and learn from them to create reasonable designs? (4) what intervention strategies should the system use for displaying enough information at the right time without disrupting the work process?, and (5) when will designers suspend the construction process and access relevant information?

Challenges for System Building. System building efforts in support of learning on demand face the

challenge of how a system can relinquish control of task selection yet maintain knowledge of users' goals, plans, and background knowledge. How can such systems be designed to function effectively in huge and potentially non-determinable solution spaces? Our work addresses this problem by modeling problem domains with design environments. Rather than representing solutions to individual problems, design environments support contextualized information access which has as its goal to deliver the right knowledge, in the context of a problem or service, at the right moment for a human professional to consider. A partial understanding of the task at hand (as expressed by a partial specification and a partial construction) allows the system to prioritize information spaces in support of learning on demand [Fischer, Nakakoji 91].

Systems that allow learning to take place within the context of real problem-solving situations must avoid the "production paradox" [Carroll, Rosson 87], where learning is inhibited by lack of time and working is inhibited by lack of knowledge. Learners must regard the time and effort invested in learning to be immediately worthwhile for the task at hand—not merely for some putative long-term gain.

Limitations of Learning on Demand. Beyond the possibilities that learning on demand can offer, one should not overlook a number of limitations: (1) the acquisition of certain essential skills should not be deferred until they are needed, because the time to learn them may be not available or the environment may be too dangerous for safe learning processes; (2) learning on demand is task driven and therefore may be limited to exposing users to isolated pieces of knowledge providing only limited support for learning essential principles; (3) users may encounter difficulties in decontextualizing knowledge so that it can be used in new settings, and (4) whereas learning on demand may be well suited for evolutionary extensions of a knowledge base, it may not support substantial restructuring because the additional features learned occur only in the neighborhood of what learners already know.

4 Conclusions

Learning on demand is necessary because learning in advance is no longer feasible in our high-technology world. More research needs to be done to determine whether learning on demand differs from other types of learning and, in particular, whether it is more or less effective. This will require a combination of psychological and computer science research, because learning on demand cannot be studied in isolation from systems supporting it, and support systems cannot be built without understanding the psychological mechanisms of learning on demand. Learning on demand may overcome some problems of schooling which alienate students from the world treating learning as an activity separate from the rest of life. Learning on demand is what truly sets computer-based environments apart from other media—and it may therefore be a unique research direction where technology can make a real difference in achieving new educational objectives and overcome basic limitations of our current educational approaches.

References

[Akscyn, McCracken, Yoder 88]
R.M. Akscyn, D.L. McCracken, E.A. Yoder, *KMS: A Distributed Hypermedia System for Managing Knowledge in Organizations*, Communications of the ACM, Vol. 31, No. 7, July 1988.

[Bereiter, Scardamalia 89]
C. Bereiter, M. Scardamalia, *Intentional Learning as a Goal of Instruction*, in L.B. Resnick (ed.), *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1989, pp. 361-392, ch. 12.

[Brown, Palincsar 89]
A.L. Brown, A.S. Palincsar, *Guided, Cooperative Learning and Individual Knowledge Acquisition*, in L.B. Resnick (ed.), *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1989, pp. 393-451, ch. 13.

[Carroll, Rosson 87]
J.M. Carroll, M.B. Rosson, *Paradox of the Active User*, in J.M. Carroll (ed.), *Interfacing Thought: Cognitive Aspects of Human-Computer Interaction*, The MIT Press, Cambridge, MA, 1987, pp. 80-111, ch. 5.

[Dews 89]
S. Dews, *Developing an ITS in a Corporate Setting*, Proceedings of the 33rd Annual Meeting of the Human Factors Society (Denver, CO), 1989, pp. 1339-1342.

[Draper 84]
S.W. Draper, *The Nature of Expertise in UNIX*, Proceedings of INTERACT'84, IFIP Conference on Human-Computer Interaction, Elsevier Science Publishers, Amsterdam, September 1984, pp. 182-186.

[Fischer et al. 88]
G. Fischer, S.A. Weyer, W.P. Jones, A.C. Kay, W. Kintsch, R.H. Trigg, *A Critical Assessment of Hypertext Systems*, Human Factors in Computing Systems, CHI'88 Conference Proceedings (Washington, DC), ACM, New York, May 1988, pp. 223-227.

[Fischer et al. 90]
G. Fischer, A.C. Lemke, T. Mastaglio, A. Morch, *Using Critics to Empower Users*, Human Factors in Computing Systems, CHI'90 Conference Proceedings (Seattle, WA), ACM, New York, April 1990, pp. 337-347.

[Fischer, Lemke 88]
G. Fischer, A.C. Lemke, *Construction Kits and Design Environments: Steps Toward Human Problem-Domain Communication*, Human-Computer Interaction, Vol. 3, No. 3, 1988, pp. 179-222.

[Fischer, Lemke, McCall 90]
G. Fischer, A.C. Lemke, R. McCall, *Towards a System Architecture Supporting Contextualized Learning*, Proceedings of AAAI-90, Eighth National Conference on Artificial Intelligence, AAAI Press/The MIT Press, Cambridge, MA, August 1990, pp. 420-425.

[Fischer, Lemke, Schwab 85]
G. Fischer, A.C. Lemke, T. Schwab, *Knowledge-Based Help Systems*, Human Factors in Computing Systems, CHI'85 Conference Proceedings (San Francisco, CA), ACM, New York, April 1985, pp. 161-167.

[Fischer, McCall, Morch 89]
G. Fischer, R. McCall, A. Morch, *JANUS: Integrating Hypertext with a Knowledge-Based Design Environment*, Proceedings of Hypertext'89 (Pittsburgh, PA), ACM, New York, November 1989, pp. 105-117.

[Fischer, Nakakoji 91]
G. Fischer, K. Nakakoji, *Making Design Objects Relevant to the Task at Hand*, Proceedings of AAAI-91, Ninth National Conference on Artificial Intelligence, AAAI Press/The MIT Press, Cambridge, MA, 1991, pp. , forthcoming.

[Greeno 89]
J.G. Greeno, *Situations, Mental Models, and Generative Knowledge*, in D. Klahr, K. Kotovsky (eds.), *Complex Information Processing: The Impact of Herbert Simon*, Lawrence Erlbaum Associates, Hilldale, NJ, 1989, pp. 285-318, ch. 11.

[Halasz 88]
F.G. Halasz, *Reflections on NoteCards: Seven Issues for the Next Generation of Hypermedia Systems*, Communications of the ACM, Vol. 31, No. 7, July 1988, pp. 836-852.

[Kintsch 88]
W. Kintsch, *The Role of Knowledge in Discourse Comprehension: A Construction-Integration Model*, Psychological Review, Vol. 95, 1988, pp. 163-182.

[Lave 88]
J. Lave, *Cognition in Practice*, Cambridge University Press, Cambridge, UK, 1988.

[Lemke, Fischer 90]
A.C. Lemke, G. Fischer, *A Cooperative Problem Solving System for User Interface Design*, Proceedings of AAAI-90, Eighth National Conference on Artificial Intelligence, AAAI Press/The MIT Press, Cambridge, MA, August 1990, pp. 479-484.

[Papert 80]
S. Papert, *Mindstorms: Children, Computers and Powerful Ideas*, Basic Books, New York, 1980.

[Papert 86]
S. Papert, *Constructionism: A New Opportunity for Elementary Science Education*, Proposal to The National Science Foundation, MIT - The Media Laboratory, Cambridge, MA, 1986.

[Resnick 89]
L.B. Resnick, *Introduction*, in L.B. Resnick (ed.), *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1989, pp. 1-24, ch. 1.

[Riesbeck, Schank 89]
C. Riesbeck, R.C. Schank, *Inside Case-Based Reasoning*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1989.

[Schoen 83]
D.A. Schoen, *The Reflective Practitioner: How Professionals Think in Action*, Basic Books, New York, 1983.

[Sculley 89]
J. Sculley, *The Relationship Between Business and Higher Education: A Prespective on the 21st Century*, Communications of the ACM, Vol. 32, No. 9, September 1989.

[Suchman 87]
L.A. Suchman, *Plans and Situated Actions*, Cambridge University Press, Cambridge, UK, 1987.

[Wenger 87]
E. Wenger, *Artificial Intelligence and Tutoring Systems*, Morgan Kaufmann Publishers, Los Altos, CA, 1987.

[Weyer 87]
S.A. Weyer, *As We May Learn*, Multimedia in Education: Interfaces to Knowledge, Education Advisory Council Conference Proceedings, Apple Computer, April 1987, pp. 87-103.

[Winograd, Flores 86]
T. Winograd, F. Flores, *Understanding Computers and Cognition: A New Foundation for Design*, Ablex Publishing Corporation, Norwood, NJ, 1986.