

Design, Learning, Collaboration and New Media

A Co-Evolutionary HCI Perspective

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Abstract

This paper focuses on creating a new understanding of design, learning and collaboration (as fundamental human activities) and their support with innovative computational media and technologies. A co-evolutionary HCI perspective explores the dialectical relationship between (a) the unique potential of computational media to create true innovations impacting and transforming design, learning, and collaboration by transcending "gift-wrapping" approaches and (b) how a deep understanding of design, learning, and collaboration creates innovative demands and design criteria for future generations of HCI systems.

Keywords

design, learning, collaboration, new media, co-evolution, open systems, domain-oriented design environments, high-functionality applications, critiquing

1. Introduction

Our research in HCI has been centered for many years on creating human-centered computational environments empowering humans to think, design, learn and collaborate in new ways. These environments (1) have explored new and different relationships between humans and computers; (2) have acknowledged the asymmetry between humans and computers; and (3) have emphasized knowledge representations for human understanding rather than for machine efficiency.

Our work on collaborative human-computer environments has been firmly grounded in the *complementary approach* rather than *emulation or replacement approach* [Terveen, 1995]. The complementary approach is focused not only on simulating how humans design, learn and collaborate but of inventing innovative alternatives and extensions

based on a co-evolutionary perspective. The fundamental challenges of this approach are: (1) to specify a division of labor between human and computer by asking which part of the task should be exercised by human beings and which part by computers [Billings, 1991], and (2) to design a communication protocol that can be used to coordinate and mutually enhance the collaborative efforts.

In doing so, we have created theoretical frameworks and prototype systems to contribute toward the establishment of the scientific foundations of HCI by understanding the information processing potential and limitations of humans and new media. We believe that our efforts are significant not only as transcendent technical achievements in computer science, but that they have led to a new understanding of design, learning, and collaboration.

In this paper, I will discuss problems that motivate this approach; describe my understanding of design, learning, and collaboration; illustrate innovative media with examples of the work in our Center for LifeLong Learning and Design (L³D), and provide a brief assessment of the approach.

2. Problems

Beyond Objective Computability. A fundamental question in HCI is not what users can do in principle (objective computability)—what matters is what users can do in practice (subjective computability). The epistemological adequacy of formalism from an HCI perspective is primarily not a formal or theoretical issue but a cognitive issue. For many problems, the question of subjective computability is more relevant than whether a problem is computable in theory.

Beyond Ease of Use. By studying and exploring new interactions and relationships between humans and computers, HCI is more than user interfaces and more than "screen-deep" [Computer Science and Technology Board - National Research Council, 1997]: it is a multidisciplinary field covering many areas [Helander et al., 1997]. In the first ten to fifteen years of its history, HCI has focused on interfaces (particularly on the possibilities and design criteria for graphical user

interfaces (GUIs) using windows, icons, menus, and pointing devices (WIMPs)) to create more *usable* systems. As interface problems were better understood, the primary HCI concerns started to shift beyond the interface (to respond to an observation by D. Engelbart: "If ease of use was the only valid criterion, people would stick to tricycles and never try bicycles"). More recent HCI research objectives [Fischer, 1993; Terveen, 1995] are concerned with tasks, shared understanding, explanations, justifications, and argumentation, and not just with interfaces.

Beyond Closed Systems. One fundamental challenge for the design of the interactive systems of the future is to invent and design environments as open systems in which humans can express themselves and engage in personally meaningful activities. Unfortunately, a large number of new media are designed from a perspective of viewing and treating humans primarily as consumers [Fischer, 1998a]. The opportunity for humans to be and act as designers should be accessible not only to a small group of "high-tech scribes," but rather to all interested individuals and groups (if such activity is meaningful to them). Open systems should give skilled domain workers and discretionary users sufficient control over their computational environments.

Beyond Gift-Wrapping. The possibilities and the practice of design, learning and collaboration are a function of the media used in these activities. We are specifically interested in how to transcend "gift-wrapping" approaches, such that new media are not used only to present old content and old processes in new packages. For example:

- How can computational media, specifically HCI techniques, be used to address the information overload problem by supporting an "attention economy" rather than an "information economy"?
- How can HCI techniques change the nature of the reflective conversation between designer and the materials of the situation by providing active design materials that increase the "talk-back" of the design situation [Schön, 1983].
- How can HCI techniques support the co-evolution of problem framing and problem solving?
- How can HCI techniques support designers to identify breakdowns that they may not be aware of

and how can breakdowns be turned into opportunities for creative actions [Fischer, 1999]?

- How can HCI techniques support design in specific domains rather than just generic design activities? Skilled domain workers are specialists who want to work in their own conceptual world.
- How can we design for change and evolution? Evolution of complex systems is a ubiquitous phenomenon [Curtis et al., 1988].

3. The Co-Evolutionary Nature

Skilled workers engaged in problem-solving and design activities need useful and usable systems. Creating such systems requires that system designers focus on: the usability of tools, the expressiveness or power of tools, how well the tools are suited to the domain, what processes are involved in applying and adapting tools, and how people understand problems and develop solutions. Complex relationships exist among people, media and tools, and problems. One of the crucial aspects of these relationships is their co-evolutionary nature:

- new media influence and change our understanding of design, learning, and collaboration and new approaches towards design, learning, and collaboration lead to new requirements for media
- people adapt their practices and problem-solving approach to the affordances of the tool, and people adapt their tools to better support their practices and problems [Ehn, 1988; Mackay, 1991].

Figure 1 relates design, learning, and collaboration with the problems discussed above, the emphasis that our research gives to these problems and mentions the specific developments efforts further discussed below.

4. Examples: L³D Contributions

Three examples will be presented:

- *design* approaches illustrated by domain-oriented design environments;
- *learning* approaches illustrated by high-functionality applications and critiquing systems; and
- *collaboration* approaches illustrated by the Envisionment and Discovery Collaboratory.

activity	problems addressed	emphasis of our research	examples of new media
design	beyond objective computability	collaborative human-computer system; design conceptualized as reflection-in-action	domain-oriented design environments
learning	beyond ease of use	lifelong learning; learning on demand; integration of working and learning	high-functionality applications; critiquing
collaboration	beyond closed systems	computer-supported collaborative work and learning	open systems; seeding, evolutionary growth, reseeding;

Figure 1. Problems Addressed by our Research

4.1. Design: Domain-Oriented Design Environments

Orienting software systems towards specific domains or tasks has been heralded by many researchers as a means of making software both more useful and more usable [Fischer, 1994; Nardi, 1993]. Domain-oriented software is more usable than generic software because users directly interact with familiar entities and do not need to learn new computer-specific concepts. It is more useful than generic software because the provided functionality directly targets tasks relevant to the domain and users do not have to build up desired behaviors from other lower-level operations.

Domain-oriented design environments are a family of software programs that support not only human-computer interaction, but human problem-domain communication, making the computer invisible and bringing tasks to the forefront. Domain-oriented design environment (Figure 2 illustrates these different support mechanisms with an example in the area of computer network design) empower individuals by:

- letting them articulate a partial description of their tasks with the help of a *specification component* (see Pane 4);
- supporting the creation of an artifact with a

- construction worksheet* (see pane 2 and 3);
- providing *domain objects* supporting design by composition (see Pane 2);
- using a *catalog* of previous designs supporting design by modification (see Pane 5);
- signaling potential breakdowns with a *critiquing component* (not shown in this screen image);
- supporting the exploration of *argumentation and design rationale* (see Pane 1); and
- providing additional feedback with a *simulation component* (see Pane 3).

4.2. Learning: High-Functionality Applications and Critiquing Systems

To cope with the complexity of real world problems, designers use high functionality applications (such as Unix, MS-Office, PhotoShop, Eudora, etc.). Each of these applications is a complex system because it serves the needs of large and diverse user populations. The broad requirements for knowledge workers (e.g., a multimedia designer who must deal with text, color, sound, film, animations, etc.) require that they use a number of different high functionality applications and because individuals have difficulty to learn and use just one of these systems, the mastery of a number of them creates formidable learning problems. Many approaches

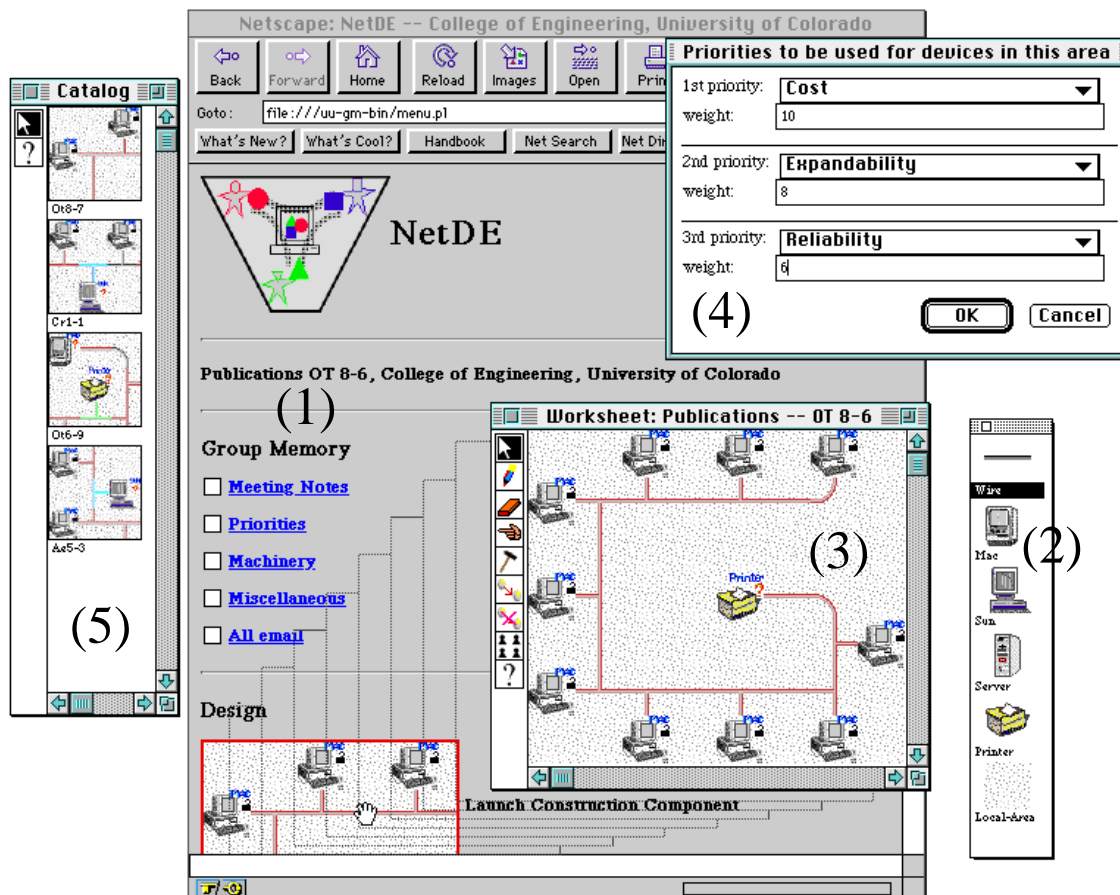


Figure 2. A Domain-Oriented Design Environment for Computer Network Design

that represented major advances in human-computer interaction, such as direct manipulation [Hutchins et al., 1986; Shneiderman & Maes, 1997] lose some of their power in high functionality applications in which the complex and abundant functionality can neither be represented explicitly on the screen nor be explored by browsing mechanisms.

The design of HFAs must address three problems: (1) commonly used functionality should be not too difficult to learn, use, and remember, (2) unknown existing functionality must be accessible or delivered at times when it is needed; and (3) the unused functionality must not get in the way. We have conducted a variety of empirical studies to determine the usage patterns of HFAs, their structure, and their associated help and learning mechanisms. All of these studies have shown that people do not learn HFAs completely and that they often contain substantial functionality whose existence is unknown to users. For these parts of the system, information access (requiring the user to initiate the process) is not sufficient, but information delivery (the system volunteering information that it inferred to be relevant to the users' task at hand) is required. Active help systems and critics are required to point out to users functionality that may be useful for their tasks and to help users avoid getting stuck on suboptimal plateaus.

To address these learning challenges, we have developed a number of computational environments [Fischer, 2000] illustrating these ideas, including:

- *active help systems* exploring the limitations of tool-based systems. These systems analyzed the user's actions and proposed alternative ways of doing a task by suggesting functionality possibly unknown to the user;
- *critics* analyzing work products created by designers to infer the task at hand in order to be able to detect shortcomings and identify potentially relevant information contained in the system;
- *learning on demand* and integration of working and learning allowing users to acquire new information in the context of authentic activities;
- *specification components* [Nakakoji, 1993] that allow users to enrich the description of their tasks; and
- information retrieval components that use the artifact (including domain knowledge, its partial construction and partial specification) as an indication of the user's intentions, thereby providing an opportunity to infer high-level goals from simple user action [Nardi et al., 1998].

Critiquing Systems. As people take on more jobs that are more complex or more comprehensive, they need help accomplishing unfamiliar tasks that are part of an expanded job. For example, in multi-media design, designers have HFA at their disposal that allow them to use thousands of colors, packages for producing graphs, etc. But many of the designers using these HFA know little about the domains: e.g., how and when to use color efficiently or how graphs can be used to convey the relevant information [Tuft, 1990] rather than mislead the users. This problematic issue illustrated in the

domain of graphs is described by Kosslyn [Kosslyn, 1994] as follows: *"one reason for the abundance of bad graphs is the proliferation of low-cost microcomputers and "business graphics" packages which often seduce the user into producing flashy but muddled displays; many graphs are designed without consideration of principles of human perception and cognition"*.

While books, such as the ones by Tuft and Kosslyn provide guidance and principles for the respective domains, this information (which is currently only available in the static medium of books) is not related to the tasks and the work products created by a designer. *Critiquing systems* (especially when they are embedded in domain-oriented design environments [Fischer et al., 1998]) support reflection-in-action [Schön, 1983] and help designers to not just create a work product, but "good" work products obeying and possibly transcending the accumulated knowledge of a community of practice.

4.3. Collaboration: The Envisionment and Discovery Collaboratory

Complex design activities cannot be solved by isolated individuals. Such activities require not only collaboration among multiple individuals within a discipline, but among multiple disciplines, as well. *Communities of practice* [Wenger, 1998] are groups of practitioners who work as a community in a certain domain doing the same kind of work (although within each community there are individuals with special expertise, such as power users and local developers [Nardi, 1993]). *Communities of interest* (CoIs) are groups of people from different backgrounds coming together to solve a particular design problem. Examples of CoIs are: (1) software development teams that includes software designers, marketing specialists, psychologists, and programmers, (2) urban design teams to plan and implement new transportation systems, and (3) the HCI community itself bringing together researchers and practitioners from many different fields. Fundamental challenges facing CoIs are to build a shared understanding of the task at hand (which often does not exist beforehand, but is evolved collaboratively and emerges in people's mind and in external artifacts). Members of CoIs need to learn to communicate with and learn from others who have a different perspective and a different vocabulary for describing their ideas and establish a common ground and a shared understanding. *Boundary objects* are needed that communities of interests can communicate effectively, create a shared understanding of the emerging problem, and that all stakeholders are empowered to actively contribute and critique constructively the contribution of stakeholders coming from other communities of practice.

The Envisionment and Discovery Collaboratory (EDC) [Arias et al., 2000] is an environment integrating a large number of HCI approaches and techniques to support CoIs (see Figure 3). The EDC framework is applicable to different domains, but our initial effort has focused on the domain of urban design, specifically in

transportation planning and community development. Creating shared understanding requires a culture in which stakeholders see themselves as reflective practitioners rather than all-knowing experts [Schön, 1983]. The "asymmetry of knowledge" is a defining characteristic of such collaborative design activities: stakeholders are aware that while they each possess relevant knowledge, none of them has all the relevant knowledge.

Figure 3 shows the current realization of the EDC environment. Individuals using the EDC convene around a computationally enhanced table, shown in the forefront of the figure. This table serves as the *action space* for the EDC. Currently realized as a touch sensitive surface, the action space allows users to manipulate the computational simulation projected on the surface by

simulations to allow users to engage in "what-if" games; (4) creating co-evolutionary environments, in which stakeholders change because they learn, and in which systems evolve because stakeholders become co-developers and engage in end-user modification; and (5) allowing stakeholders feel in control and accept roles of active contributors rather than passive consumers [Fischer, 1998a].

The Seeding, Evolutionary Growth, Reseeding (SER) Model. In the context of the EDC designers create and evolve systems over time. The seeding, evolutionary growth, reseeded (SER) model [Fischer, 1998b] supports this process. In the SER model, system developers and users develop an initial *seed* designed to be extended. Because it is impossible to capture any design activity completely, the seed must be able to



Figure 3. The Envisionment and Discovery Collaboratory (EDC)

interacting with the physical objects placed on the table. Another touch-sensitive (vertical) whiteboard serves as the EDC's *reflection space*. The reflection and action spaces are connected using the Web as a medium. The entire physical space, through the immersion of people within the representations of the problem-solving task, creates an integrated human-computer system grounded in the physical world.

Most current HCI efforts are still focused on the "single user/single computer" interaction model. The EDC emphasizes the creation of shared interaction and the cultural embedding for learning and design within the context of CoIs. The EDC explores innovative HCI techniques by (1) exploiting the asymmetry of ignorance as a source of power for mutual learning; (2) increasing the "back-talk" of the artifacts with critics; (3) using

grow through use. As the seed is used for real design activity, it goes through a period of *evolutionary growth* in which all stakeholders make incremental modifications to the system over time. Because evolution is driven by the work of the users, there must be mechanisms available that allow *users* to make necessary changes.

Experiences with open systems show that it will become necessary to reseed the system. Reseeding is a complex process that requires assessing, synthesizing, and reconceptualizing the current system. The result of the reseeded process is a new system that can serve as the basis for future evolution. The cycle of evolution and reseeded continues stakeholders continue using the system to solve problems.

5. Future Challenges

Beyond Current Assessment Approaches. The last 15 years of HCI research has focused on novice users, emphasizing rigorous quantitative research. Typical studies involved subjects who use a system or prototype to accomplish a task, which may be manipulated by researchers as part of the study. These usability studies were performed in laboratories, where experiments can be closely controlled. Subjects were not familiar with the tasks, but the tasks were in general simple enough to be learnt quickly. The future of HCI needs to be more concerned with the *skilled user*. Our goal is to support professional designers, and the problems that designers face are different. Professional domains are complex, designers work in them for years, which make it impossible to do meaningful empirical investigations with novices.

Beyond Closed Systems. In purely technical domains, *open-source software* [O'Reilly, 1999] has emerged as an interesting example of successful open systems. Powerful tools such as the Linux operating system and the Apache Web server have become both useful and reliable in large part because of the evolutionary contributions of a large community of motivated developers. The open-source approach regards software and other cognitive artifacts not as a commodity to be consumed, but one that is collaboratively designed and constructed—providing a model for the knowledge society of the future. In the past, open systems have been successful when technically oriented people created technically oriented software. To create open systems for stakeholders who are not skilled nor interested in technical domains is an important challenge for the future. HCI frameworks need to be developed that break down the boundaries between software designer and users by allowing users to act as co-developers.

Beyond Consumers. Collaboration and the evolutionary growth postulated by the SER model is impossible in communities where most members regard themselves as consumers [Fischer, 1998a]. Individuals must have the opportunity to evolve into power-users and co-developers who use and at the same time are able to modify and extend artifacts if that is meaningful to them. After all, software as already indicated by its name, should be "soft." One of the major contributions that information technology can lend to the world is to understand and exploit the potential of the malleable nature of software in which knowledge is no longer handed down from above, but instead is constructed collaboratively in the context of work.

Understanding Delegation. Arguing for the desirability for people to be designers and not just consumers requires a deep understanding of delegation in a society characterized by a division of labor. *Delegation is desirable* when the delegator does not possess the knowledge or skill required to accomplish a task directly (after all, we rely heavily on professional expertise in many domains), and when the task can be specified in enough detail to be entrusted to someone else.

Professional expertise has its place—if it is used properly.

Empowering all stakeholders by reducing the reliance on high-tech scribes does not mean denying the value of specialization and division of labor. *Delegation is not desirable* in many design tasks, because design deals with ill-defined problems, and it proceeds through incremental steps of creating artifacts and reflecting upon the results by being a reflective conversation between the designer and the materials of the design situation. In the case of collaborative design, involving many people working together to make sense of a problem, design becomes a conversation in the more literal sense because designers use the design media not only to facilitate a conversation with the design situation, but also with other designers.

Addressing the Challenges of HFAs. As the complexity of commercially available HFAs grows, and as we see more computational assistants (such as agents, advisors, coaches, and critics) appear in widely available commercial applications, an analysis and understanding of how people learn, design, and collaborate with and around HFAs will provide us with new requirements for HCI. Microsoft, with its IntelliSense software components, started to tackle the problems of HFAs in its commercial applications. Other commercial system components acting as critics, such as spelling and grammar checks, could be made considerably more useful by integrating them into system architectures as explored by domain-oriented design environments.

Many HFAs allow users to create additional features by supporting end-user programming with macros and embedded (simple programming or scripting) languages. Based on adequate HCI support, the success of these features has been rather limited.

Filling some Gaps in HCI Research. For each of the three activities discussed in this paper, one major dimension can be identified in which substantially more HCI research is needed in the future:

- a *change and evolution perspective* is missing from *design*, because users, artifacts, tasks, work, organizations change and substantially more research is needed about co-adaptive systems, and the evolutionary design of complex systems;
- a *lifelong learning perspective* is missing from *learning*, emphasizing the integration of working and learning, and support for self-directed learning, learning on demand, and collaborative learning;
- a *motivation perspective* is missing from *collaboration*, informing us what will make users want to share and how to close the gap between who is beneficiary and has to do the work in a collaborative setting.

Coming to Terms with the Mindset Issue. Research in HCI, especially if we want to move beyond the "gift wrapping" approach, will have fundamental long-term societal impacts. It will force us to reinvent how we think, design, learn, and collaborate.

This research will provide us with opportunities to explore fundamentally new possibilities and limitations of computational media as they complement existing media. It will force us to think about new concepts for

collaboration such as sustainable communities. It will pose the question of how large complex information spaces can be evolved over long periods of time, not by their professional designers but by their affected users. It will enrich the notion of collaborative human computer systems, allowing us to draw different lines between what humans should do and what machines should do.

6. Conclusions

One may argue that our current thinking does not address the potential magnitude of the problem. Have we arrived at a point where the change in human existence and human behavior with respect to media is of a similar magnitude to the time when our society moved from an oral to a literary society (and Socrates and Plato were arguing about the trade-offs associated with this change) or when Gutenberg's printing press eliminated the scribes and gave everyone the opportunity to become literate? The fact that societies have often overestimated change in the short run and underestimated it in the long run suggests that we should make every effort to understand the perspective how new media and human activities can co-evolve—and which contributions HCI can make to this objective. While computational media have inspired the "information revolution," a deeper understanding of human abilities and human communities is needed to make it a reality.

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8. References

- [1] Arias, E. G., Eden, H., Fischer, G., Gorman, A., & Scharff, E. (2000) "Transcending the Individual Human Mind—Creating Shared Understanding through Collaborative Design," *ACM Transactions on Computer Human-Interaction*, 7(1), pp. 84-113.
- [2] Billings, C. E. (1991) *Human-Centered Aircraft Automation: A Concept and Guidelines*, NASA Technical Memorandum, Report No. 103885, NASA Ames Research Center.
- [3] Computer Science and Technology Board - National Research Council (Ed.) (1997) *More Than Screen Deep: Toward Every-Citizen Interfaces to the Nation's Information Infrastructure*, National Academy Press, Washington, D.C.
- [4] Curtis, B., Krasner, H., & Iscoe, N. (1988) "A Field Study of the Software Design Process for Large Systems," *Communications of the ACM*, 31(11), pp. 1268-1287.
- [5] Ehn, P. (1988) *Work-Oriented Design of Computer Artifacts*, Almquist & Wiksell International, Stockholm, Sweden.
- [6] Fischer, G. (1993) "Beyond Human Computer Interaction: Designing Useful and Usable Computational Environments." In *People and Computers VIII: Proceedings of the HCI'93 Conference (Loughborough, England)*, Cambridge University Press, Cambridge, UK, pp. 17-31.
- [7] Fischer, G. (1994) "Domain-Oriented Design Environments," *Automated Software Engineering*, 1(2), pp. 177-203.
- [8] Fischer, G. (1998a) "Beyond 'Couch Potatoes': From Consumers to Designers." In IEEE (Ed.) *1998 Asia-Pacific Computer and Human Interaction, APCHI'98*, IEEE Computer Society, pp. 2-9.
- [9] Fischer, G. (1998b) "Seeding, Evolutionary Growth and Reseeding: Constructing, Capturing and Evolving Knowledge in Domain-Oriented Design Environments," *Automated Software Engineering*, 5(4), pp. 447-464.
- [10] Fischer, G. (1999) "Social Creativity, Symmetry of Ignorance and Meta-Design." In L. Candy & E. Edmonds (Eds.), *Proceedings of Creativity & Cognition 1999*, ACM Press, New York, pp. 116-123.
- [11] Fischer, G. (2000) "User Modeling in Human-Computer Interaction," *User Modeling and User-Adapted Interaction, Dordrecht, The Netherlands: Kluwer Academic Publishers*, (to appear).
- [12] Fischer, G., Nakakoji, K., Ostwald, J., Stahl, G., & Sumner, T. (1998) "Embedding Critics in Design Environments." In M. T. Maybury & W. Wahlster (Eds.), *Readings in Intelligent User Interfaces*, Morgan Kaufmann, San Francisco, pp. 537-561.
- [13] Helander, M. G., Landauer, T. K., & Prabhu, P. V. (Eds.) (1997) *Handbook of Human-Computer Interaction*, (Second, Completely Revised ed.), Elsevier Science Ltd., Amsterdam.
- [14] Hutchins, E. L., Hollan, J. D., & Norman, D. A. (1986) "Direct Manipulation Interfaces." In D. A. Norman & S. W. Draper (Eds.), *User Centered System Design, New Perspectives on Human-Computer Interaction*, Lawrence Erlbaum Associates, Inc., Hillsdale, NJ, pp. 87-124.
- [15] Kosslyn, S. M. (1994) *Elements of Graph Design*, W.H. Freeman and Company, New York.
- [16] Mackay, W. E. (1991) "Triggers and Barriers to Customizing Software." In S. P. Robertson, G. M. Olson, & J. S. Olson (Eds.), *Proceedings of CHI'91 Conference on Human Factors in Computing Systems*, ACM, New York, pp. 153-160.
- [17] Nakakoji, K. (1993) *Increasing Shared Understanding of a Design Task Between Designers and Design Environments: The Role of a Specification Component*, Ph.D. Dissertation, Department of Computer Science, University of Colorado at Boulder, Boulder, CO.
- [18] Nardi, B. A. (1993) *A Small Matter of Programming*, The MIT Press, Cambridge, MA.
- [19] Nardi, B. A., Miller, J. R., & Wright, D. J. (1998) "Collaborative, programmable intelligent agents," *Communications of the ACM*, 41(3), pp. 96-104.
- [20] O'Reilly, T. (1999) "Lessons from Open Source Software Development," *Communications of the ACM*, 42(4), pp. 33-37.
- [21] Schön, D. A. (1983) *The Reflective Practitioner: How Professionals Think in Action*, Basic Books, New York.
- [22] Shneiderman, B. & Maes, P. (1997) "Direct Manipulation vs. Interface Agents," *Interactions (ACM)*, 4(6 (Nov)), pp. 42 - 61.

[23] Terveen, L. G. (1995) "An Overview of Human-Computer Collaboration," *Knowledge-Based Systems Journal, Special Issue on Human-Computer Collaboration*, 8(2-3), pp. 67-81.

[24] Tufte, E. R. (1990) *Envisioning Information*, Graphics Press, Cheshire, CT.

[25] Wenger, E. (1998) *Communities of Practice — Learning, Meaning, and Identity*, Cambridge University Press, Cambridge, England.