Computational Literacy and Fluency: Being Independent of High-Tech Scribes

Gerhard Fischer, University of Colorado, Boulder

Abstract

In the middle ages, most people were dependent on "scribes", who helped them to write down their thoughts, ideas, and stories, as well as to read the material written by other people. Many people today are in the same situation with respect to digital media: they are unable to express themselves, explore problem spaces, appropriate tools, and act as designers in *personally meaningful tasks*. They have to rely on "high-tech scribes". This chapter explores new conceptual frameworks and innovative computational environments that support people in becoming *independent* of "high-tech scribes".

Introduction

This chapter explores the relationship between humans and media [Engelbart, 1995; McLuhan, 1964], assuming that the main function of all collective cultural activity is to produce "works and oeuvres" [Bruner, 1996]. Externalizing our thoughts and ideas rescues cognitive activity from implicitness, making it more public, negotiable, and shared. The greatest milestone in the history of externalization was reading and writing, which allowed people (who were literate) to document and disseminate their ideas on paper.

Our research is based on the belief that the potential change of digital media for computation, communication, and collaboration, with the important additional functionality that digital representation can be interpreted by computers, will be of a magnitude of importance similar to the introduction of reading and writing.

The *digital divide* [Schön et al., 1999] has often been discussed as the difference between owning and having access to modern information technology (IT) and not. Although access is necessary, however, it is not sufficient. For example, putting every school on the Internet may be necessary to achieve certain objectives, but it is not sufficient to improve learning and teaching. We subscribe to Barron's argument that *"the discourse has rapidly shifted from a concern about who has access to new information technologies to who will* *have the knowledge that will position them to design, create, invent, and use the technologies to enhance their personal lives and social worlds"* (p1 in [Barron, 2004]). The ideas, assumptions, hypotheses, and findings in this chapter are based on my involvement over the last three decades to co-evolve our understanding of learning, teaching, and collaborating, taking into account the impact of new media and the change in learning organizations. My involvement started in the early 1970s when I joined the community of researchers who believed that the biggest impact of computers would not be to use them as teaching machines, but to put learners in charge and let them explore their own ideas [Boecker et al., 1991; Papert, 1980]. In order to explore our own ideas, however, we need to be fluent with IT and not dependent on high-tech scribes.

Literacy and Fluency with Digital Media

Media can and should serve as extensions of humans. The history of the human race is one of ever-increasing intellectual capability. Since the time of our early ancestors, our brains have gotten no bigger, and our hands no more skillful nor stronger, but there has been a continuous accumulation of new tools for physical and intellectual work.

Literacy. Literacy with digital media [National-Research-Council, 1999] has often been characterized and practiced in our educational institutions to teach learners to acquire keyboarding skills or a degree of competency with some of today's computer applications (e.g., word processing, email, html, drawing programs, etc.). It has focused on teaching learners to generate syntactically correct expressions with the primary concern on form rather than content. The limitations of this kind of literacy are that it lacks conceptual understanding, it is ill-suited to cope with change (e.g., no migration path to new skills are developed), and it prevents people from using digital media for personally meaningful problems.

Fluency. Fluency with IT is defined as *"the ability to reformulate knowledge, to express oneself creatively and appropriately, and to produce and generate information rather than simply to comprehend it"* [National-Research-Council, 1999]. Fluency goes beyond traditional notions of computer literacy by requiring a deeper, more essential understanding and mastery of IT, and it is a prerequisite to creating a personal and deep relationship with media [Kay, 1984]. Fluency is characterized by different levels of sophistication. In addition, it is dynamic and changes over time, requiring an engagement in lifelong learning. Fluency should not be reduced to formalized knowledge about programming, especially if programming is understood as writing step-by-step "recipes", as it has been mostly conceptualized in the past. Fluency certainly should include contemporary skills such as using existing applications, but it should further be supported by digital media that allow users to tailor, customize, and evolve systems to their wants in personally meaningful tasks [Fischer, 2002].

In the past, most initiatives to improve fluency have focused on school classrooms, but there is a growing recognition that informal learning settings can play an important role in promoting fluency. Informal learning is often more self-directed, voluntary, and motivated by intrinsic interests, curiosity, exploration, and social interaction than formal learning. Informal learning settings are well positioned to leverage young people's passion for new technologies as a starting point for developing technological fluency. Fluency flourishes best in communities of practice in which learners can share their ideas and experiences [Wenger, 1998].

Digital media in support of fluency must not only be available, they must also (1) support a discourse at the level of problem domains and not just at the computer domain; (2) be objects of critical reflection, open to adjustment and tweaking; (3) support unintended and subversive uses (not just anticipated ones); (4) must not be too resistant to being torn apart and reconceived; and (5) allow learners to engage in personally meaningful activities. Innovative uses of digital media will transcend and exploit the unique properties of computational media that are absent in principle in printed media. Printed media *do not have interpretive power* — they can convey information, but they cannot analyze the work products created. For example, *simulation* is a process that can show us the implications of our assumptions and allow us to engage in "what-if" problem solving, whereas *critiquing* is a process that *analyzes our work products* and increases the "back-talk" of an artifact by presenting a reasoned opinion about it [Fischer et al., 1998].

Being Independent of High-Tech Scribes

To make fluency a realistic goal, though, computing needs to be deprofessionalized [Illich, 1973]. The monopoly of highly trained computing professionals acting as "high-tech scribes" should be eliminated, just as the monopoly of the scribes was eliminated during the Reformation in Europe. This does *not* mean that there is no place for professional programmers and system designers in the future; it does mean, however, that one of the most important objectives of the professional computing community should be to create systems that will put *owners of problems* in charge [Fischer & Giaccardi, 2004].

Achieving the goal of putting problem owners in charge is not only a technical problem, it represents a considerable social effort. If the most important role for computation in the future is to provide people with a powerful medium for expression, then the medium should support them in working on the task, rather than requiring them to focus their intellectual resources on the medium itself.

Software systems that require little domain knowledge can be delegated to professional software developers after the domain experts (users) have identified the requirements and handed the development task to them. This process exploits the strength of the *division of labor* [Brown & Duguid, 2000; Levy & Murnane, 2004], in which software developers and domain experts work in their own professional domains and concentrate on what they know and do best. This approach, however, works only for the cases in which the problems are well defined and the requirements can be well understood and clearly expressed in advance of the development of the systems. When the requirements can be only partially understood or defined previous to the construction of the system, professional software developers need to work in close collaboration with domain experts (a system design methodology pursued in *participatory design approaches* [Schuler & Namioka, 1993]).

Most complex problems are *ill-defined problems* that cannot be delegated because they require the *integration of problem framing and problem solving* [Rittel, 1984], making it impossible to define requirements in advance. Ill-defined problems require that the *"back-talk"* [Fischer et al., 1998; Schön, 1983] of a problem goes to the owners of the problem to help them iteratively gain a deeper understanding of the problem during the process of constructing the solution. Domain experts use computers to create solutions to the problems they own and that are meaningful to them.

Domain experts representing owners of problems are neither novices nor naive users. They are people who have computational needs and use computers by choice and over extended periods of time. Due to their lack of interest in computers per se and lack of training in software development, they *often develop software systems in an ad hoc way without appropriate knowledge about software engineering principles and methodologies*. Domain experts are not interested in becoming professional software developers; for them, software systems are *means, not ends*; they have neither the desire nor the time to become professional software engineers.

Example: A Success Story of Digital Media Serving Personally Meaningful Problems

Many years ago, I taught an extra-curricular course for gifted high-school students to explore the use of digital media for personal empowerment. One of the students attending the course informed me at the very beginning that he was not interested in mathematics (making the standard assumption that digital media require a standard mathematical mindset), and therefore he was not particularly interested in this course. But because almost all of his friends were attending the course, he decided that he would come along (at least for the time being).

The student remained invisible in the course until we suggested creating a program that would generate poetry. To our surprise, the student "fell in love" with this project (just as other people fall in love with gears [Papert, 1980], or with craft technology, referring to the interweaving of computation with craft materials [Eisenberg, 2004]).

The student worked diligently for many weeks on his project and was rewarded for his efforts not only by the encouragement of the class, but also when the local newspaper printed an article about our research project and featured one of his poems (see Figure 1).

Der Dumme Student

Das dumme Stubenmaedchen verflucht die Schlampe
das lustige Kindermädchen verbrennt keine Pampe
jedes kluge Mädchen ionisiert den Tresen
ein verschrumpeltes Mädchen verbrennt das Wesen
kein ausgereifter Professor kocht den Wurm
kein aufgespießter Student besteigt den Turm.

Der kleine Hausmeister elektrisiert einen Ball

jedes schweinslederne Mädchen seziert einen Knall
der gefriergetrocknete Bergsteiger erfreut das Bier
jede erdrosselte Jungfrau untersucht einen Stier
ein kleiner Computer massakriert jede Flasche
jeder erdrosselte Mann bearbeitet die Asche.

Figure 1: A Computer-Generated Poem

The underlying program at the time was written in LOGO [Papert, 1980], using a syntactic sentence structure

```
<article> <adjective> <noun> <verb> <article> <noun>
```

and the individual grammatical categories were represented as lists such as

```
<noun> = "Asche Ball Bergsteiger Computer......."
```

In his ongoing effort to further improve the program, the student generated many poems and analyzed them. One of these analyses led him to the unexplained phenomenon that some words occurred much more frequently than others, and he asked us whether we would know why this may be the case.

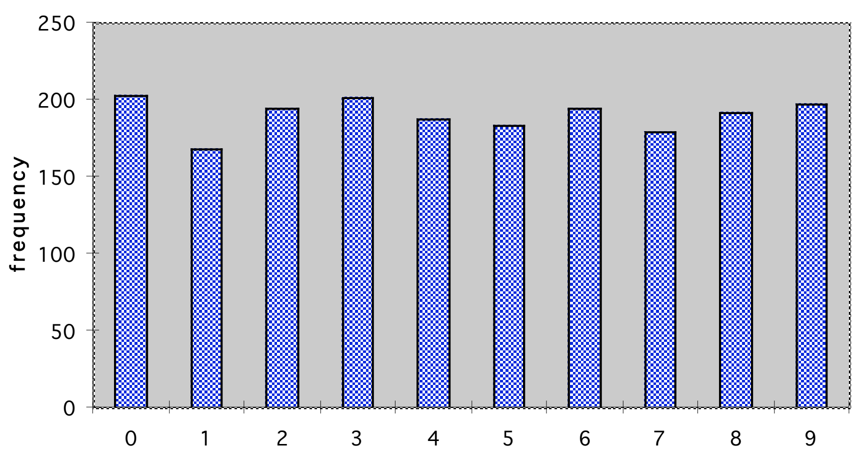

Figure 2: Distribution of the results returned by the built-in function "`RANDOM`"

Although we did not know the answer immediately, we eventually developed a conjecture for it. But rather then telling him the answer, we engaged him in *guided discovery learning* [Mayer, 2004], providing him with guidance for self-exploration. The student was using a random number generator (which returned a value between 0 and 9) to select words from his lists of word categories, but his lists were of arbitrary length (for simplification, we assume that they were of 0 to 19), and he used some form of `SUM RANDOM RANDOM` for coping with these longer lists. We encourage him to develop some programs to visualize the effects of this process for a sufficiently large number of selections. He created these programs and he was surprised by the visualization of the results, shown in *Figure 2* and *Figure 3*.

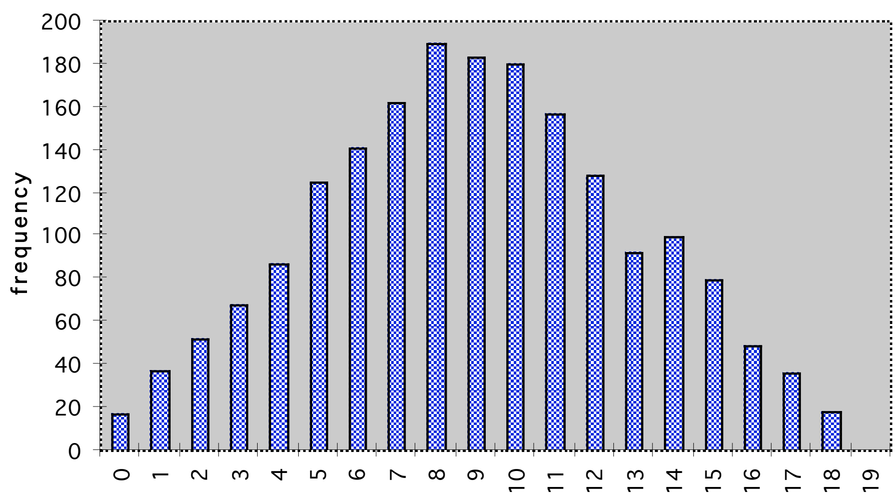

Figure 3: Distribution of the Results from "`SUM RANDOM RANDOM`*"*

We encouraged him to explore the results of "`WORD RANDOM RANDOM`" (which concatenates the two numbers returned by `RANDOM`; the results need to be adjusted for the range of 0 to 19 instead of 0 to 99) instead of using `SUM`. The results of this process are shown in *Figure 4*.

Lessons to Be Learned from the Story. The student (who told us that he suffered from "math phobia" when he first met us) had rediscovered essential elements of probability theory, namely, the difference between functions whose resulting values are *uniformly* distributed (as in `RANDOM` and `WORD RANDOM RANDOM`) versus *non-uniform* distributions (as in `SUM RANDOM`

RANDOM). He did so based on his own intrinsic motivation; he studied and worked hard on this problem not because he *had* to, but because he *wanted* to. His participation in this course turned out to represent not only a change in his mindset (he developed a great interest in certain aspects of mathematics), but a life-changing event: he decided to study computer science and became a successful computer scientist in his professional life.

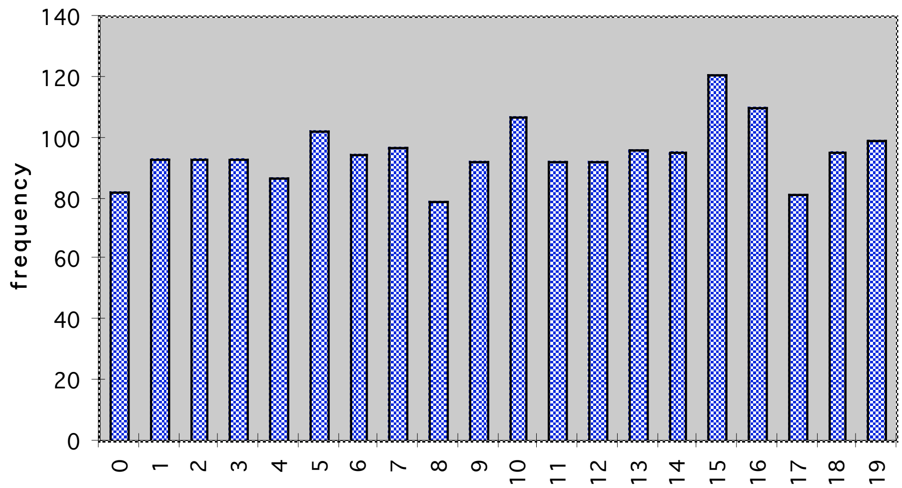

*Figure 4: Distribution of the Results from "*WORD RANDOM RANDOM*"*

Reflections

We will use our framework of computational fluency and our example to draw a few general conclusions about the relationship between new media and a new understanding of learning, teaching, and collaboration.

Co-Evolution between Media and Content

Gift-Wrapping. Many uses of new media can be characterized as *"gift-wrapping":* they are used as add-ons to existing practices rather than a catalyst for fundamentally rethinking what education should be about in the next century [Fischer, 1998]. They change the medium, but leave the content unchanged. For example, the "innovation" of making transparencies available on the World-Wide Web (WWW) rather than distributing copies of them in a class takes advantage of the WWW. This may change the economics of teaching and learning, but it contributes little to introducing new epistemologies. “Old” frameworks, such as instructionism, fixed curricula, memorization, decontextualized learning, and so forth, are not changed by technology itself. This is true whether we use computer-based training, intelligent tutoring systems, multimedia presentations, or the WWW. We need computational environments to support “new” frameworks for education such as lifelong learning, integration of working and learning, learning on demand, authentic problems, self-directed learning, information contextualized to the task at hand, (intrinsic) motivation, collaborative learning, and organizational learning.

Examples of “gift-wrapping” are ubiquitous: (1) using computers to teach the same mathematics; (2) using e-books that deliver content identical to printed versions; (3) “webifying” courses by putting the same course materials on the web that were formally distributed in paper form; and (4) conceptualizing distance learning as classroom learning at a distance.

Changing Content. Another one-sided approach with limited success is changing the content without creating more fitting new media. One of the best known examples of this approach is the introduction of “New Math” [Morris, 1974] in the 1970s. Other examples falling into this category are: (1) nonlinear text published on paper (e.g., documents with lots of embedded footnotes, references, annotations, indexes); and (2) groupware servers that merely provide shared repositories (the old medium being a file system) instead of providing a new medium that helps users to relate to the contents of the information resources and construct new ones.

Co-Evolution. The limitations of the two one-sided approaches provide the foundation for co-evolutionary approaches in which new content and new media fit each other. Examples in this category are turtle geometry [Papert, 1980]; simulation environments; hypermedia; craft technologies [Eisenberg, 2004]; and interactive art [Fischer & Giaccardi, 2004].

Division of Labor

This chapter argues for the independence of owners of problems from high-tech scribes. A legitimate question to ask is whether this will reverse the *division of labor* [Levy & Murnane, 2004], which has been a major driving force in advancing our societies. Professional designers play an important role in our society — the "average" person does not want to build her/his own houses, design her/his own car, or write her/his own software system or sorting routine. People do not have the time to participate equally in all aspects of human life in order to become fully engaged and informed, and therefore they rely on intermediaries to act in their interests. Learners who want to become competent in multiple fields face formidable challenges: the need to deal with enormous and increasing knowledge bases and the lack of belonging to a well-established community of practice.

We therefore restrict our argument to personally meaningful problems. These are the problems idiosyncratic to individuals for which they care enough to be involved. For these problems, the experience of having participated makes a difference to those who are affected by the solution. People are more likely to like a solution if they have been involved in its generation, even though it might not make sense otherwise [Rittel, 1984].

Making people independent of high-tech scribes supports reflection-in-action as a problem-solving approach [Schön, 1983]. Ill-defined problems cannot be delegated: in creative problem solving, learners and knowledge workers do not know in advance what they want before they start. The creative process is in creating situations that talk back, which leads to a variety of interim "solutions" and modifications of the original problem, thereby supporting the integration of problem framing and problem solving.

Meta-Design

In a world that is not predictable, improvisation, evolution, and innovation are more than luxuries — they are necessities. The challenge of design is not a matter of getting rid of the emergent, but rather of including it and making it an opportunity for more creative and more adequate solutions to problems. Many design approaches force all the design intelligence to the earliest part of the design process, when everyone knows the least about what is really needed. Meta-design is a conceptual framework in which new forms of collaborative design can take place. End-user modifiable systems provide the enabling conditions for putting owners of problems in charge. Breakdowns in such environments are experienced by the end users and not by the system builders. End users need the ability to continually and directly evolve and refine their information space, without relying on "high-tech scribes". End-user modifiable systems extend the traditional notion of system design beyond the original development of a system to include an ongoing process in which the users of the system become co-developers. The most important roles for the high-tech scribes of the future should be that they act as meta-designers, creating the socio-technical environments in which learners of all ages and all professions can act as informed participants in the context of personally meaningful problems. Meta-designers use their own creativity to produce socio-technical environments in which other people can be creative. They define the technical and social conditions for broad participation in design activities, which are as important as creating the artifact itself.

Meta-design is more than a technical problem: it addresses the challenges of fostering new mindsets, new sources of creativity, cultural changes, and innovative societies. It has the potential to create a culture in which all participants in collaborative design processes can express themselves and engage in personally meaningful activities.

"Basic" Skills in the Age of Digital Media

If distributed cognition is the most promising framework to educate learners for a productive life, one needs to ask: What are the "basic" skills in the age of digital media? For most knowledge domains (1) *coverage* is impossible and (2) *obsolescence* is inevitable [Eisenberg & Fischer, 1993]. The result is a need for socio-technical environments in which unknown demands are encountered, requiring that new knowledge be learned on demand.

If these observations are adequate descriptions of the problems facing learners and workers of all ages, then we need to ask the following questions and find principled answers for them: (1) If most job-relevant knowledge must be learned on demand, what is the role of "basic" education? (2) What is the critical background knowledge that makes learning on demand feasible? (3) Do "basic" skills change their meaning under the influence of technology? Furthermore, concerning cognitive tools such as handheld calculators, spelling checkers, grammar programs, Mathematica, under which conditions should they be *tools for living* (i.e., people rely on their existence and availability to perform certain tasks) or *tools for learning* (i.e., people will become independent of them)? Both tools for living and those for learning, as powerful media to extend our human abilities, require fluency to be successfully exploited in framing and solving personally meaningful problems.

Conclusions

The context for human development is always a culture, never an isolated technology. Our current cultures largely move in the direction of making learners increasingly independent of high-tech scribes. Many learners have acquired true computational fluency by growing up with digital media as a primary representation for thinking, learning, working, and collaborating. The right kind of socio-technical environments (bringing people and media together) will allow learners to become independent of high-tech scribes in the context of personally meaningful problems.

Acknowledgements

The author thanks the members of the Center for LifeLong Learning & Design at the University of Colorado, who have made major contributions to the conceptual framework and systems described in this paper.

The research was supported by (1) the National Science Foundation, Grants (a) REC-0106976 “Social Creativity and Meta-Design in Lifelong Learning Communities”, and (b) CCR-0204277 “A Social-Technical Approach to the Evolutionary Construction of Reusable Software Component Repositories”; (2) SRA Key Technology Laboratory, Inc., Tokyo, Japan; (3) the Coleman Institute, Boulder, CO.

References

Barron, B. (2004) "Learning Ecologies for Technological Fluency: Gender and Experience Differences," *Journal Educational Computing Research,* 31(1), pp. 1-36.

Boecker, H., Eden, H., & Fischer, G. (1991) *Interactive Problem Solving Using Logo,* Lawrence Erlbaum Associates, Inc., Hillsdale, NJ.

Brown, J. S., & Duguid, P. (2000) *The Social Life of Information,* Harvard Business School Press, Boston, MA.

Bruner, J. (1996) *The Culture of Education,* Harvard University Press, Cambridge, MA.

Eisenberg, A. (2004) *Craft Technology Group,* Available at http://www.cs.colorado.edu/~ctg/.

Eisenberg, M., & Fischer, G. (1993) "Symposium: Learning on Demand." In *Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society*, Boulder, CO, pp. 180-186.

Engelbart, D. C. (1995) "Toward Augmenting the Human Intellect and Boosting Our Collective IQ," *Communications of the ACM,* 38(8), pp. 30-33.

Fischer, G. (1998) "Making Learning a Part of Life—Beyond the 'Gift-Wrapping' Approach of Technology." In P. Alheit, & E. Kammler (Eds.), *Lifelong Learning and Its Impact on Social and Regional Development,* Donat Verlag, Bremen, pp. 435-462.

Fischer, G. (2002) *Beyond 'Couch Potatoes': From Consumers to Designers and Active Contributors, in FirstMonday (Peer-Reviewed Journal on the Internet),* Available at http://firstmonday.org/issues/issue7_12/fischer/.

Fischer, G., & Giaccardi, E. (2004) "Meta-Design: A Framework for the Future of End User Development." In H. Lieberman, F. Paternò, & V. Wulf (Eds.), *End User Development — Empowering people to flexibly employ advanced information and communication technology,* Kluwer Academic Publishers, Dordrecht, The Netherlands, p. (in press).

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. 537-559.

Illich, I. (1973) *Tools for Conviviality,* Harper and Row, New York.

Kay, A. C. (1984) "Computer Software," *Scientific American,* 251(3), pp. 52-59.

Levy, F., & Murnane, R. J. (2004) *The New Division of Labor: How Computers are Creating the Next Job Market,* Princeton University Press, Princeton.

Mayer, R. E. (2004) "Should There Be a Three-Strikes Rule Against Pure Discovery Learning? — The Case for Guided Methods of Instruction," *American Psychologist,* 59(1), pp. 14-19.

McLuhan, M. (1964) *Understanding Media: The Extensions of Man,* The MIT Press, Cambridge, MA.

Morris, K. (1974) *Why Johnny Can't Add: The Failure of the New Math,* Random House.

National-Research-Council (1999) *Being Fluent with Information Technology,* National Academy Press, Washington, DC.

Papert, S. (1980) *Mindstorms: Children, Computers and Powerful Ideas,* Basic Books, New York.

Rittel, H. (1984) "Second-Generation Design Methods." In N. Cross (Ed.), *Developments in Design Methodology,* John Wiley & Sons, New York, pp. 317-327.

Schön, D. A. (1983) *The Reflective Practitioner: How Professionals Think in Action,* Basic Books, New York.

Schön, D. A., Sanyal, B., & Mitchell, W. J. (Eds.) (1999) *High Technology and Low-Incoming Communities,* MIT Press, Cambridge, MA.

Schuler, D., & Namioka, A. (Eds.) (1993) *Participatory Design: Principles and Practices,* Lawrence Erlbaum Associates, Hillsdale, NJ.

Wenger, E. (1998) *Communities of Practice — Learning, Meaning, and Identity,* Cambridge University Press, Cambridge, UK.