Computational Environments Supporting Creativity in the Context of Lifelong Learning and Design

Gerhard Fischer[1] and Kumiyo Nakakoji[2,3]

[1] Center for LifeLong Learning and Design (L3D)
University of Colorado, Boulder, CO

[2] Software Engineering Laboratory
Software Research Associates, Inc., Tokyo Japan

[3] Cognitive Science Laboratory
Nara Institute of Science and Technology, Japan

Contact Address:

Gerhard Fischer
CB430
Department of Computer Science
University of Colorado
Boulder CO. 80309-0430
tel: +1 (303) 492-1502; fax: +1 (303)492-2844
email: gerhard@cs.colorado.edu

Kumiyo Nakakoji
Graduate School of Information Science
Nara Institute of Science and Technology
8916-5, Takayama-cho
Ikoma-city, Nara, 630-01, Japan
tel: +81 (0)743-72-5381; fax: +81 (0)743-72-5319
email: kumiyo@is.aist-nara.ac.jp

Abstract:

Much of our intelligence and creativity results from the collective memory of communities of practice and of the artifacts and technology surrounding them. Rather than studying individual creativity in isolation, we have developed a conceptual framework of creativity in the context of everyday practice – where design activities prevail and learning is constantly required. The conceptual framework explores new role distributions between people and computers based on theories that view design as reflection-in-action and breakdowns as opportunities for learning and creativity. We use an example from the domain of multimedia information design to illustrate how creativity is supported by domain-oriented design environments. The paper describes the mechanisms, architectures and processes underlying these environments.

Keywords: Creativity Support, Domain-Oriented Design Environments (DODEs), Lifelong-Learning

Short Title: Creativity in the Context of LifeLong Learning and Design

INTRODUCTION

While creativity is often associated with art, we are concerned with creativity that is required in everyday work practice. This type of creativity is in most cases not historical, but psychological [1]. A resulted product is not necesarily novel or original to a community but is personally or psychologically novel to the individual who produced it. While analyzing outstanding creative people [2] contributes towards establishing a framework for individual creativity, understanding creativity in the context of social everyday activities is equally important for letting people become more productive and create better work products.

In the work presented here, we focus our study of creativity on design activities with an emphasis on the importance of lifelong learning. The analysis of everyday design practices [3] has shown that knowledge workers and designers have to engage in creative activities in coping with the unforseen complexities of everyday, real-world tasks.

While considering descriptive accounts of creativity as an important foundation of our approach, the focus of our work is to build computational environments which augment and empower the creative potential of individuals and groups who belong to a community of practice. The approach is based on a conceptual and technical framework that supports:

- distributed cognition by exploring new role distributions between people and computers,
- task-relevant reminding, learning on demand, and end-user modifiablity by contextual elaboration,
- reflection-in-action by making argumentation serve design,
- breakdowns and symmetry of ignorance by seeing them as opportunities,
- integration of problem framing and problem solving by regarding solution attempts as contributing to the incremental understanding of a problem, and
- collective creativity by integrating knowledge-delivery and end-user modifiability.

Based on the above framework, we have developed over the last decade domain-oriented design environments (DODEs) to support creativity in the context of design and lifelong learning. Starting with a discussion on design, lifelong learning and creativity in the social context, the paper then presents the eMMa (Environment for MultiMedia Authoring) system, a DODE for multimedia information design, as an example to illustrate how creativity is supported by domain-oriented design environments and describes the mechanisms, architectures and processes underlying these environments.

DESIGN, LIFELONG LEARNING AND CREATIVITY

Design and Lifelong Learning

The world of professional design activity is complex, uncertain, unstable, unique, and full of conflicting value judgements [4, 5, 6]. The central theme of our conceptual framework is the use of design as a vehicle for understanding psychological creativity [1]. In pursuing this theme, we take the notion of "design" in its broadest and richest sense. Design has long been a staple of many professions—architecture, engineering, playwriting, landscaping, sculpture—but with the advent of what Drucker [7] refers to as the "knowledge worker" in technology-based economies, design has become an almost ubiquitous element of professional practices. Chemists design new molecules; biochemists design new genes; graphic artists design custom charts; business people design spreadsheet models.

This increase in design activity has been accompanied by the growth of supporting technologies, which, on one hand, can lead to more powerful and expressive work products, but on the other hand, may make work practice increasingly complex and difficult to learn. Lifelong learning is an indispensable process in everyday practice.

Design activities and lifelong learning should be integral components to environments that support people's work. Design provides a perspective that weaves the acquisition of knowledge into meaningful activity, which takes place in rich social contexts and over extended periods of time. Creativity in design plays a critical role in cultivating learning in design activities.

Creativity

The relation of people to their work is important for understanding creativity (please note that in the context of this paper, we limit our discussion on the work designing with a computational environment). Creativity is not a result of a one-shot affair but an outcome of continuous efforts of discovering and evaluating alternatives. In iteratively discovering and evaluating alternatives, a creative individual seeks a balance between the following tensions necessary to lead to creative products (see Table 1):

Table 1: Tensions in Creativity

value	useful	novel (unusual for its own sake)
discovery	serendipitous	presumed relevance
importance	appropriate/trivial	unknown
structuring	orderly rules	chaos
conservance	tradition	transcendance
rules	following	breaking
guidance	constraints	freedom

First, balance between usefulness and innovativeness needs to be made for a product to be creative. The product must be novel so that it is not a part of existing well-known solution. On the other hand, if the product is not useful, or of little value, it cannot be regarded as creative. The other tensions are related to types and properties of information that can be weaved into a creative product. Often, information that leads into a creative product is regarded as a result of serendipitous encounter [8]. However, studies have shown that information necessary to come to a creative product is often deeply related to the problem that the one is coping with. In terms of the importance of the information, if the importance is so obvious, it is likely to lead to a well-known solution - not creative. On the other hand, whether the information can be important for creativity cannot be presumed a priori. Following orderly rules based on a traditional approach tends to lead to a product that is useful, but not necessarily novel. To transcend the tradition, one needs to take a chaotic approach by breaking rules, which, however, has less chance to produce a useful product.

To find the "right" balance between these tensions, one outsources information, such as books and other people, which we call collective creativity.

Collective Creativity

The power of the unaided, individual mind is highly overrated. A creative activity is not only performed as an individual but placed in the social context. Much of our intelligence and creativity results from the collective memory of communities of practice and of the artifacts and technology surrounding them. Though creative individuals are often thought of working in isolation, the role of interaction and collaboration with other individuals is also critical [9]. Thus, creative activity grows out of the relationship between an individual and the world of his or her work, and out of the ties between an individual and other human beings.

Learning takes place not only from textbooks, but by addressing real world problems. Our goal is to help people give more opportunities to be creative by unleashing the creative potential with computational environments. Thus, creativity and learning form two sides of a coin. To be creative, one needs to obtain new ways to look at existing artifacts and concepts from outside sources – learning is required to be creative. In contrast, creative products will bring along innovative viewpoints of the products allowing people to become aware of new perspectives – learning takes place as a result of creative processes.

In what follows, we present our approach to support creativity by integrating learning within the context of design, real-world practices in social context.

CREATIVITY AND COMPUTATIONAL ENVIRONMENTS

> "You cannot use smoke signals to do philosophy.
> Its form excludes the content."
> (Postman, "Amusing Ourselves to Death", p 7)

There are shortcomings in current computational environments to support creativity. Existing approaches do not take into account the tensions illustrated in Table 1. Most creativity support tools have goals along one side or the other, but not both. In effectively supporting individual creativity in design, a support tool needs to integrate both ends of the tensions, allowing people to find their own balance in the spectrum.

Let us take a look at the "right" amount of functionality that a system should provide. Take the use of color on a computer display as an example. While current computer displays can present millions of colors, they do not necessarily lead users to produce creative multimedia titles or computer graphics. On the contrary, usable support tools (in the wrong hands) lead to products of reduced quality - "one reason for the abundance of bad graphs is the proliferation of low-cost mini-computers and `business graphics' packages" [10; p2]. Moreover, such a rich set of functionality allow inappropriate color usage, which can be harmful by not understanding psychological effects of color.

With these challenges in mind, we have explored the use of computer systems to support creativity in the context of everyday practice as design activities where people engage themselves in lifelong learning. This section presents our conceptual and technical framework in more detail.

New Role Distributions Between People and Computers

All media have always had an impact on creativity, and creativity has produced new media. In this most general view, there is not much new about the impact of the computer. When looking for its peculiar kind of influence, we have to identify the unique features of the computer.

It has often been said that with the computer, artists, designers, or architects may easily play with hundreds of variations. Since part of creative work is indeed based on fiddling around with the elements of a repertoire, computers have an impact on the combinatorial aspects of creativity. For example, Karl Sims has built a system that automatically generates virtual creatures that move and behave in physically simulated three-dimensional worlds by genetically computing the morphology [11]. Combinatorics, however, is only one aspect of creativity. Our goal is to support other aspects of creativity, which are concerned with semantics and meanings of artifacts by using computers as medium that leads people to creative thinking.

``Creativity is a function of a medium" [12]. Current computer systems deprive people of potential creativity by requiring them to do tasks for manipulating computer systems themselves, not directly relevant to their work domain. To better support creativity, computer systems need to be designed to minimize efforts required to use the systems' functionality not directly relevant to designer's work domains (see Figure 1). Domain-oriented design environments (DODEs) are computational media that allow people to be engaged in more authentic tasks in their work practices by allowing them to deal with domains, not to fight with tools. Domain-oriented systems make computers invisible and enable users to communicate with the problem domain rather than with computer tools.

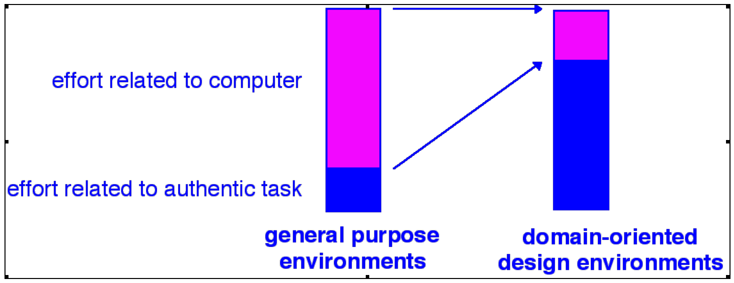

Figure 1: Focusing on the Task

Contextual Elaboration

Computer systems can go beyond paper and pencil by actively supporting people's work. When work is done using a domain-oriented design environment, the system can use artifacts produced in the environment to partially understand the context that the designer is engaged in [13].

The computer system, then, can use the representation as a query to retrieve information from its information repository. Such information is relevant to the user's current task to some extent, serving as a reminder to the task. In this manner, the system can go beyond a serendipitous information provider. At the same time, such information automatically identified as relevant and delivered to users can be learned by users. Since the information is related to what the users are currently engaged in, it is easy for them to understand and associate it with their current concern. Such learning-on-demand is the best way to support lifelong learning in the constructionism manner.

Making Argumentation Serve Design

Schoen [6] describes that design is an iterative process of action and reflection. A designer creates a design move, which creates a design situation talking back to the designer, uncovering dimensions of the design task. Design is not a rule-oriented logical activity but a series of discovering emerging features and arguing about the situations. As such, discussions and arguments about design do not preserve their semantics if isolated from relevant artifacts. Although recording design rationale and design processes are known to play an important role in creative design, such rationale needs to be embedded within the context of design. Domain-oriented design environments allow designers to record argumentation within the system in accordance with intermediate design artifacts.

Breakdowns and Symmetry of Ignorance as Opportunities

Design is collaborative in nature [13]. Design requirements and knowledge necessary to solve the design task is distributed among stakeholders. There is a "symmetry of ignorance" among the stakeholders who often experience communication breakdowns because each stakeholder belongs to different work cultures, who use different norms, symbols and representations [14]. Rather than viewing this symmetry of ignorance as an obstacle during the design, the DODE approach views it as an opportunity for creativity. Having different viewpoints helps one discover alternatives and uncover tacit aspects of the problem to cope with.

Integration of Problem Framing and Problem Solving

To support creativity, the importance and benefit of articulating goals and problem requirements in a computational design environment, whether they are formally represented or not, should be emphasized for two reasons [15]. First, the use of external representations helps designers lessen the burden of mental creation, and discover alternative interpretations for their task gaining understanding of the task. *Putting ideas down on paper is not a matter of emptying out the mind but of actively reconstructing it, forming new* *associations, and expressing concepts in linguistic, pictorial, or any explicit representational forms while lessening the cognitive load required for remembering them* [16]. The second point for having an explicit representation for a problem is that a partially represented problem specification and a partially constructed solution represents the design situation that the designers are engaged in – what we call ``the designers' task at hand" [13]. A computational environment can use this information as a query to retrieve information relevant to the identified task at hand. Multimedia authors do not have to formulate query or browse an information space to access necessary information. The system ``delivers" information for authors supporting them "seeing" a partially framed multimedia design task.

Integration of Knowledge Delivery and End-User Modifiability

Computational environments can serve as a knowledge medium, through which people can communicate over a long period of time, serving as a community that embraces collective creativity. A DODE supports two mechanisms, knowledge-delivery and end-user modifiability, the integration of which allow users to asynchronously collaborate over a long period of time [13]. Knowledge delivery is a techinique that identifies a user's need by contextual elaboration, and automatically retrieves information relevant to the task at hand. Our studies on the design environments have revealed that this often triggered users to react and motivate them to articulate opinions about the delivered knowledge. End-user modifiability is a mechanism that allow end-users to modify and add information and functionality to the system. Through the end-user modifiability, users store the articulated opinions, which results in the growth of system's knowledge-bases. Figure 2 illustrates how the integration of knowledge-delivery and end-user modifiability enables collective creativity.

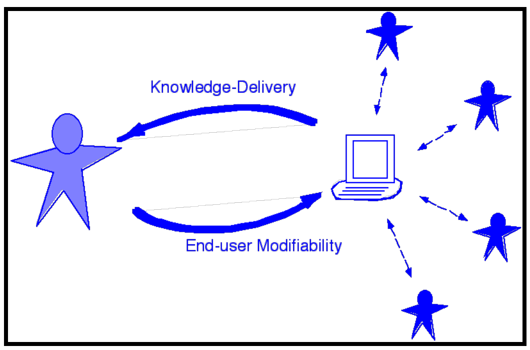

Figure 2: Integration of Knowledge-Delivery and End-User Modifiability

A DODE: A MODEL FOR COMPUTER-SUPPORTED CREATIVITY

This section presents an example of applying the DODE framework to a domain of multimedia authoring. The domain of multimedia information design is challenging for two reasons. First, there have been a number of complex tools that offer functionality so high that only professional graphic artists can use them. It is a typical domain where a technology has evolved so far ahead and people are left behind without knowing what those functionalities mean to designing multimedia titles. Second, the domain is still new, and there are no clearly stated rules or know-hows that can be shared among the community. Tips and rules-of-thumbs for designing multimedia information have been emerging over the last year [17] but are still under constant refinement and changes.

In multimedia authoring, goals vary from functional requirements (e.g., "an instruction manual for a product used mostly by elderly people" or "a conference schedule") to abstract concepts (e.g. "warm titles" or "relaxed atmosphere") to specific constraints (e.g., to use a corporate color "blue"). Authors need to *appropriately* map these intentions to detailed design decisions of authoring titles, such as color usage, sound and image associations, whether to use human- or computer-generated voice, and so on. The mapping process requires knowledge both in the domain of each media, and in the domain of "multiple-media" representations. For example, in choosing a color, there is knowledge such as "red and orange provide a warm atmosphere" [18] or "avoid red and green in the periphery of large-scale displays" [19]. Integrating multiple media requires knowledge such as "active processing of two concurrent sources of speech output would be highly stressful" or "users can attend to more than one modality if they share common topics" [20].

In the remainder of this section, we first present a scenario of using eMMa, a knowledge-based environment for multimedia authoring [21, 22]. The scenario is to illustrate how a user is supported in multimedia authoring (particularly creating a graphic image using color) in creative processes. Then we discuss an architecture of eMMa followed by a process model of using eMMa supporting collective creativity.

A Scenario with Emma

Suppose a multimedia information designer Jack wants to create a title for advertising a retreat plan for elderly people. He first specifies that he wants to create a warm atmosphere and the audience of his multimedia title would be elderly customers (see the left window in Figure 3). Then, eMMa suggests that Jack should use yellow because it is a warm color, and purple because elderly people like purple. eMMa also suggests Jack to use text size 18 point or larger because elderly people have difficulty reading small font (see the two windows on the right side in Figure 3).

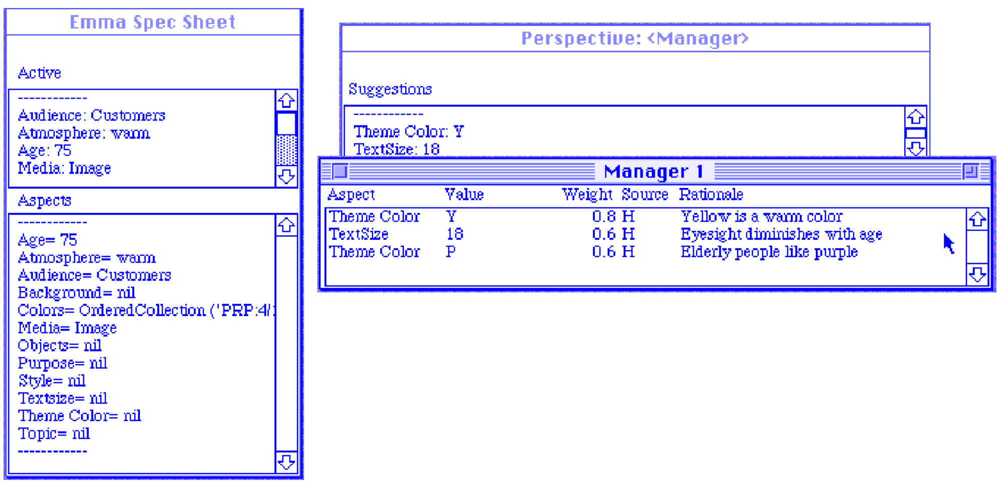

Figure 3: eMMa-SPEC

Following eMMa's suggestion, Jack decides to draw a yellow bike with purple background. eMMa then warns Jack that color combinations in terms of its area is not appropriate, and he might want to adjust to lighter purple variations (Figure 4).

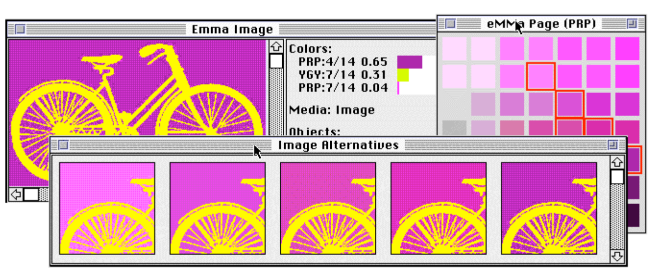

Figure 4: eMMaC: Color critics of eMMa

eMMa suggests several variations of purple to adjust

Jack selects one of the suggested purple variations, and then eMMa automatically redraws the bike image with the selected purple. Now, Jack decides to explore variations of purple. He asks for relevant images to eMMa, which retrieves images that use purple, the color that Jack used most in his drawing (Figure 5).

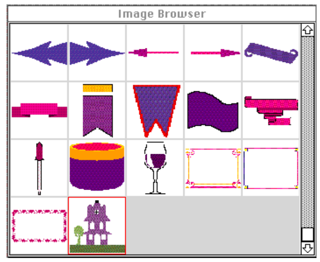

Figure 5: Image Delivery by eMMa

An image of house among the retrieved images triggered Jack to think that using house images bring in "warm atmosphere." Jack draws a house image with free-hand, and asks eMMa to retrieve similar images to his hand-drawing (Figure 6). Then, Jack wants to annotate a rationale saying that the use of houses will bring in warm atmosphere (Figure 7).

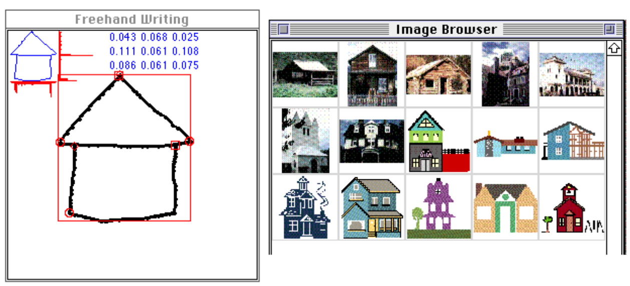

Figure 6: ImageSearcher of eMMa

Figure 7: End-user Modifiability of eMMa

eMMa Architecture

To support creative work we have developed a multi-faceted component architecture integrating construction, specification, argumentation, simulation and catalogs [23]. We have instantiated our conceptual framework and our architectures in different domains through specific operational systems supporting the creativity of stakeholders in a variety of tasks. Figure 8 illustrates the eMMa architecture, with a particular emphasis on knowledge-delivery components, a specification component, and a community knowledge-base which stores knowledge necessary to produce a multimedia title, including color theories and 1,000 images.

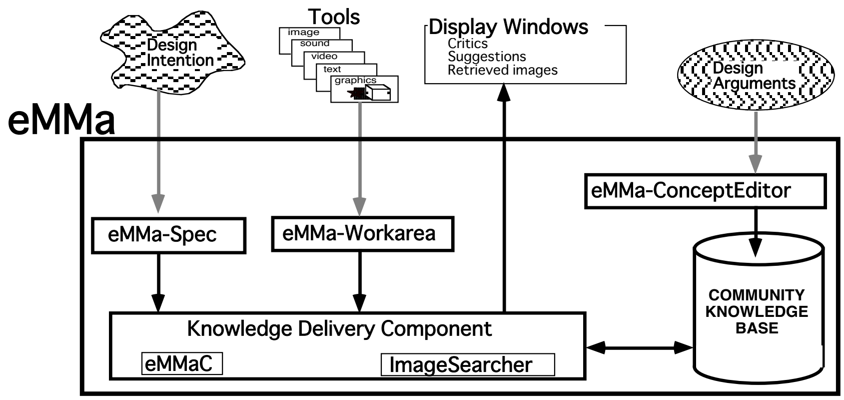

Figure 8: eMMa Architecture

The specification (eMMa-Spec) and construction (eMMa-Workarea) components allow people to produce creative products. As illustrated in the scenario, Jack specified his requirements about the type of audience and desired atmosphere. The catalog in the Community Knowledge-Base is provided to help people in the preparation phase, bringing in possible solutions and help them identify a problem space.

One of the knowledge-delivery components, eMMaC (eMMa Color Critics) [24] analyzes the use of color in a graphic image and critiques if the color is not appropriately used. Another knowledge-delivery component, ImageSearcher [25], retrieves reusable images based on a color being used in the currently constructed graphic image. In the scenario, the system automatically retrieved purple images because the dominant color used in Jack's bike image was purple. Once Jack is brought into a particular point in an information space, Jack can start exploring related information space. Creative discovery is supported by unexpected retrieval of information.

Finally, when Jack realizes that house icons will provide "warm" atmosphere, this is Jack's psychological creativity – and Jack is motivated to articulate and annotate this discovery. End-user modifiability component of eMMa (called eMMa-Concept Editor) supports Jack to add this knowledge into the community knowledge-base. Later, when other users use eMMa, they can have access to newly added idea and further develop their own creative products. In this manner, creative products as well as intermediate outcomes that people create can be stored in those knowledge-bases and will support collective creativity.

A Process Model to Support Creativity

``The creative process involves the generation of a novel creative product by the individual, the evaluation of the product by the field, and the retention of selected products by addition to the domain” [9; p336]. The field is the group of gatekeepers who are entitled to select a novel idea or product for inclusion in the domain, and the domain, which consists of the symbolic system of rules and procedures that define permissible behavior within its boundaries. [9]

As argued before, design in real world situations deals with complex, unique, uncertain, conflicted, and unstable situations of practice. Design knowledge as embedded in DODEs will never be complete because design knowledge is tacit (i.e., competent practitioners know more than they can say) [26], and additional knowledge is triggered and activated by actual use situations leading to breakdowns. Because these breakdowns [27, 28] are experienced by the users and not by the developers, computational mechanisms that support end-user modifiability are required as an intrinsic part of a DODE.

We distinguish three intertwined levels the interaction of which forms the essence of our seeding, evolutionary growth, reseeding model:

- On the *conceptual framework level*, the multifaceted, domain-independent architecture constitutes a framework for building evolvable complex software systems.

- When this architecture is instantiated in a domain (e.g., multimedia authoring and kitchen design [15]), a domain-oriented design environment (representing an application family) is created on the *domain level*.

- Individual artifacts in the domain are developed by exploiting the information contained in the generic DODE.

Figure 3 illustrates the interplay of those three layers in the context of our “seeding, evolutionary growth, reseeding (SER)” model. Darker gray indicates knowledge domains close to the computer, whereas white emphasizes closeness to the design work in a domain. The figure illustrates the role of different professional groups in the evolutionary design: the *environment developer* (close to the computer) provides the domain-independent framework, and instantiates it into a DODE in collaboration with the help of the domain designers (knowledgeable domain workers who use the environment to design artifacts).

The evolution of complex systems in the context of this model can be characterized by the following major processes (details can be found in [27]):

A **seed** will be created through a participatory design process between environment developers (software designers) and domain designers (multi-media designers). It will evolve in response to its use in new design projects because requirements fluctuate, change is ubiquitous, and design knowledge is tacit. Postulating the objective of a seed (rather then a complete domain model or a complete knowledge base) sets our approach apart from other approaches in knowledge base systems development and emphasizes evolution as the central design concept.

Evolutionary growth takes place as domain designers use the seeded environment to undertake specific projects for clients. During these design efforts, new requirements may surface, new components may come into existence, and additional design knowledge not contained in the seed may be articulated. During the evolutionary growth phase, the environment developers are not present, thus making end-user modification a necessity rather than a luxury (at least for small-scale evolutionary changes). We have addressed this challenge with end-user modifiability [29, 30], and end-user programming [31, 32].

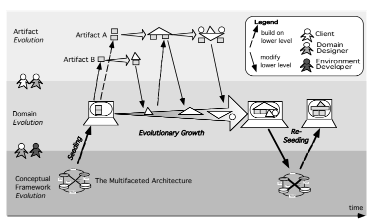

Figure 9: The SER Model

Reseeding, a deliberate effort of revision and coordination of information and functionality, brings the environment developers back in to collaborate with domain designers to organize, formalize, and generalize knowledge added during the evolutionary growth phases. Organizational concerns [33, 34] play a crucial role in this phase. For example, decisions have to be made as to which of the extensions created in the context of specific design projects should be incorporated in future versions of the generic design environment. Drastic and large-scale evolutionary changes occur during the reseeding phase.

SUMMARY

We have created computational artifacts based on the framework described above. We have developed domain-oriented design environments that bring tasks to the forefront, thereby transcending ``human computer interaction” by supporting ``human problem-domain interaction.” We support design activities by creating shared (mutually interpretable) representations between humans and computers. These shared representations allow task-based indexing of cases (in a catalog) and design rationale (in a argumentative hypermedia system). Critiquing makes argumentation serve design by increasing the back-talk of the artifact and by delivering task-relevant information. To exploit artifact, group and institutional memories and to bring design concepts into unseen and unthought, yet relevant contexts, new representations are needed to serve the task at hand. Task-relevant reminding is critical for creative activities. Because ``artifacts often do not speak for themselves," mechanisms are required to increase their back-talk.

ACKNOWLEDGEMENTS

We would like to thank the members of L3D (LifeLong Learning and Design) Center at University of Colorado at Boulder, and the members of eMMa project.

REFERENCES:

[1] Boden, M. The Creative Mind: Myths & Mechanisms, Basic Books, 1991.

[2] Gardner, H. The Mind's New Science: A History of the Cognitive Revolution, Basic Books, Inc, New York, 1985.

[3] Rogoff, B. and Lave, J. Everyday Cognition, Harvard University Press, Cambridge, MA, 1984.

[4] Rittel, H. Second-Generation Design Methods, in N. Cross (ed.), Developments in Design Methodology, John Wiley & Sons, New York, pp. 317-327, 1984.

[5] Simon, H.A. The Sciences of the Artificial, The MIT Press, Cambridge, MA, 1981.

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

[7] Drucker, P.F. The Age of Social Transformation, in The Atlantic Monthly, pp. 53-80, 1994.

[8] Roberts, R.M. Serendipity: Accidental Discoveries in Science, John Wiley & Sons, Inc., New York, 1989.

[9] Csikszentmihalyi, M. and Sawyer, K. Creative Insight: The Social Dimension of a Solitary Moment, in R.J. Sternberg and J.E. Davidson (eds.), The Nature of Insight, MIT Press, Cambridge, MA, 1995.

[10] Kosslyn, S.M. Elements of Graph Design, W.H. Freeman and Company, New York, 1994.

[11] Sims, K. Evolving Virtual Creatures, Computer Graphics (Siggraph '94) Annual Conference Proceedings, July, pp.43-53, 1994.

[12] Postman, N. Amusing Ourselves to Death, Penguin, New York, NY., 1986.

[13] Fischer, G. Nakakoji K. and Ostwald, J. Supporting the Evolution of Design Artifacts with Representations of Context and Intent, Proceedings of the Design of Interactive Systems (August), pp. 7-15, 1995.

[14] Bodker, K. and Pedersen, J. Workplace Cultures: Looking at Artifacts, Symbols and Practices, in M.K. J. Greenbaum (eds.), There's No Place Like Home: Continuing Design in Use Design at Work: Cooperative Design of Computer Systems, Lawrence Erlbaum Associates, Hillsdale, NJ, Ch. Chapter 6, 1991.

[15] Nakakoji, K. Increasing Shared Understanding of a Design Task Between Designers and Design Environments: The Role of a Specification Component, PhD dissertation, Department of Computer Science, University of Colorado, (Also available as TechReport CU-CS-651-93), 1993.

[16] Sharples, M. Cognitive Support and the Rhythm of Design, Artificial Intelligence and Creativity (T. Dartnall ed.), Kluwer Academic Publishers, the Netherlands, pp.385-402, 1994.

[17] Lynch, P.J. Yale Center for Advanced Instructional Media: World Wide Web Style Manual, http://info.med.yale.edu/caim/Manual/, 1995.

[18] Sidelinger, S.J. Color Manual, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1985.

[19] Murch, G.M. Physiological Principles for the Effective Use of Color, IEEE Computer Graphics and Arts, November, pp. 49-54, 1984.

[20] Bearne, M. Jones, S. Sapsford-Francis, J. Towards Usability Gudelines for Multimedia Systems, Proceedings of ACM Multimedia'94, ACM Press, San Francisco, CA, October, pp. 105-110, 1994.

[21] Nakakoji, K. Aoki, A. Reeves, B.N. Knowledge-Based Cognitive Support for Multimedia Information Design, Information and Software Technology, Elsevier Science, January, 1996.

[22] Nakakoji, K. Suzuki, K. Okura, N. Aoki, A. A Framework to Support Creativity in Multimedia Information Design, Proceedings of INTERACT'97, Sydney, Australia, July, 1997, (to appear).

[23] Fischer, G. Nakakoji, K. Beyond the Macho Approach of Artificial Intelligence: Empower Human Designers - Do Not Replace Them, Knowledge-Based Systems Journal, Vol. 5, No. 1, pp. 15-30, 1992.

[24] Nakakoji, K. Reeves, B.N. Aoki, A. Suzuki, H. Mizushima, K. eMMaC: Knowledge-Based Color Critiquing Support for Novice Multimedia Authors, Proceedings of ACM Multimedia'95, ACM Press, San Francisco, CA, pp. 467-476, November, 1995.

[25] Aoki, A. Nakakoji, K. Suzuki, H. Mizushima, K. Experience and Analysis of ImageSearcher in the Smalltalk Environment: an Image Retrieval System by Analyzing Properties of Images, Proceedings of the Object-Oriente Symposium'95, Japan Information Processing Society, Tokyo, Japan, June 1995, pp. 253-260, (in Japanese), 1995.

[26] Polanyi, M. The Tacit Dimension, Doubleday, Garden City, NY, 1966.

[27] Fischer, G. Turning Breakdowns into Opportunities for Creativity, in Knowledge-Based Systems, Special Issue on Creativity and Cognition, Butterworth-Heinemann, pp. 221-232, 1994.

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

[29] Eisenberg, M. and Fischer, G. Programmable Design Environments: Integrating End-User Programming with Domain-Oriented Assistance, in Human Factors in Computing Systems, CHI'94 Conference Proceedings (Boston, MA), pp. 431-437, 1994.

[30] Fischer, G. and Girgensohn, A. End-User Modifiability in Design Environments, in Human Factors in Computing Systems, CHI'90 Conference Proceedings (Seattle, WA), New York, pp. 183-191, 1990.

[31] Nardi, B.A. A Small Matter of Programming, The MIT Press, Cambridge, MA, 1993.

[32] Ambach, J. Perrone, C. and Repenning, A. Remote Exploratoriums: Combining Networking and Design Environments, Computers and Education, Vol. 24, No. 3, pp. 163-1761, 1995.

[33] Grudin, J. Interactive Systems: Bridging the Gaps Between Developers and Users, Computer, Vol. 24, No. 4, pp. 59-69, 1991.

[34] Terveen, L.G. Selfridge, P.G. and Long, M.D. From Folklore to Living Design Memory, in Human Factors in Computing Systems, INTERCHI'93 Conference Proceedings, pp. 15-22, 1993.