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Creativity Support Tools: Report From a U.S. National Science Foundation Sponsored Workshop

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Creativity support tools is a research topic with high risk but potentially very high payoff. The goal is to develop improved software and user interfaces that empower users to be not only more productive but also more innovative. Potential users include software and other engineers, diverse scientists, product and graphic designers, architects, educators, students, and many others. Enhanced interfaces could enable more effective searching of intellectual resources, improved collaboration among teams, and more rapid discovery processes. These advanced interfaces should also provide potent support in hypothesis formation, speedier evaluation of alternatives, improved understanding through visualization, and better dissemination of results. For creative endeavors that require composition of novel artifacts (e.g., computer programs, scientific papers, engineering diagrams, symphonies, artwork), enhanced interfaces could facilitate exploration of alternatives, prevent unproductive choices, and enable easy backtracking. This U.S. National Science Foundation sponsored workshop brought together 25 research leaders and graduate students to share experiences, identify opportunities, and formulate research challenges. Two key outcomes emerged: (a) encouragement to evaluate creativity support tools through multidimensional in-depth longitudinal case studies and (b) formulation of 12 principles for design of creativity support tools.

As Galileo struggled to view Jupiter through his newly built telescope, he adjusted the lenses and saw four twinkling points of light nearby. After recording their positions carefully, Galileo compared them to his drawings from previous nights. His conclusion that Jupiter had four moons circling it was a profound insight with far reaching implications.

1. INTRODUCTION

Paradigm-shifting breakthroughs make for great stories, but normal science is equally important in the evolutionary development of science, engineering, and medicine. Large and small breakthroughs are often made by scientists, engineers, designers, and other professionals who have access to advanced tools. The telescopes, microscopes, and synchrotrons of previous generations are giving way to advanced user interfaces that enable exploratory search, visualization, collaboration, and composition.

Creativity, innovation, discovery, and exploration are potent concepts in academic communities, leading companies, and visionary circles. Enthusiasts envision accelerating innovation through advanced science collaboratories, design environments, open source communities, and knowledge management tools. They promote idea generation and brainstorming tools for divergent thinking followed by knowledge organization and concept-mapping software for convergent processing. Testimonials from developers and users celebrate rapid genomic database search, shared astronomy laboratories, and potent engineering design tools. Similar enthusiasm flows from users of compelling screenwriting software, flexible music composition packages, and impressive video-editing software.

The promise of making more people more creative more of the time is compelling, but research on creativity support tools is just beginning. Proposed support tools are meant to serve individuals as they grapple with problems as well as cross-disciplinary teams working in close collaboration even when separated by distance. Even more ambitious is the provision of social creativity support tools for larger communities working in rich sociotechnical environments over longer time periods (Mumford, 2000). Expectations are high and belief in beneficial outcomes is great, but much work remains to be done to develop a respected research discipline with validated results as well as industry-oriented communities of practice with a shared vision.

Interest in creativity is growing. Computing companies, such as Hewlett-Packard feature "innovation" as their expertise, whereas Intel and Microsoft present appealing television commercials that promise to empower young minds with technology ("Your potential. Our passion."). Consulting companies claim expertise and offer seminars, software entrepreneurs promote products, and education institutions offer innovation-oriented product design degrees. Web sites promote a range of creativity support tools, novel processes, and educational seminars.

A small number of cognitive and computer scientists, information systems researchers, and industrial designers have begun to develop theories and software tools that may have widespread benefits, but their work could be dramatically accelerated with increased research support. These researchers often focus on serving professionals such as business decision makers, biologists exploring genomic databases, or designers developing novel consumer products. At the same time there is a history of collaborative projects between technologists and new media artists, musicians, poets, and writers that are inspiring new tools. For each of these projects, novel research methods could also accelerate our understanding of what software improvements are needed.

The shared assumption is that creativity can be studied using scientific methods to produce replicable outcomes, taught in a reliable way that enhances an individual's or a group's creative potential, and supported with tools that have validated benefits. These are ambitious goals, which can generate skepticism from some observers who believe that creative processes are beyond scientific study, that creative potential is innate and therefore unalterable, and that software tools often limit imagination. Other skeptics feel that because creativity has flourished for thousands of years, new software tools are not needed, or that encouraging creative-thinking skills could undermine the attraction of currently accepted structured processes.

To understand these issues and to explore opportunities for improving creativity support tools we convened a workshop of 25 research leaders (see Appendix A for the full list) to discuss design principles, evaluation methods, and meaningful challenges. The workshop report (see Appendix B for the table of contents, or see the full report at http://www.cs.umd.edu/hcil/CST) includes two major sections that discuss research methods and initial design principles for creativity support tools. To evaluate the diverse strategies used to achieve creative outcomes and to assess the benefits of creativity support tools, we stress research methods based on multidimensional in-depth longitudinal case studies (MILCs). To improve existing creativity support tools we suggest 12 principles that have proven effective in previous projects. Additional sections cover

- The relationship to new media artists, offering lessons from this community whose focus is on creative work products and environments
- The role of search tools and information visualization
- A survey of efforts around the world related to creativity tools
- Seven issues repeatedly raised during the workshop
- A review of creativity and distributed intelligence
- A set of future research directions

The primary audience for this article includes research managers in government, industry, and universities as well as researchers interested in exploring these new directions. Secondary audiences include educators, students, software developers, and potential users. In the remainder of this article we review current thinking about creativity, discuss the challenge of choosing research methods, present the 12 design principles, and describe the workshop outcomes.

2. CURRENT THINKING ABOUT CREATIVITY

The potential for enhancing human creativity has been a recurring theme of visionary thinkers such as Edward de Bono (1973), whose "lateral thinking" ideas have had a warm response internationally but a cool reception from academics. De Bono's methods have been adopted by national education commissions and are widely taught in industry. Dan Couger's (1996) review of 22 creativity methods included the classic ones such as the methods described by Jacques Hadamard, reporting on Henri Poincare: Preparation, incubation, illumination, verification.

Recent variations include these design steps for engineering that are increasingly taught explicitly and becoming part of commercial product design life cycles (Adams, Turns, & Atman, 2003; Atman, Turns, Cardella, & Adams, 2003):

- Problem definition—identify need
- Gather information
- Generate ideas—brainstorm and list alternatives
- Modeling—describe how to build
- Feasibility analysis
- Evaluation—compare alternatives
- Decision—select one solution
- Communication—write or present to others
- Implementation

In professional communities there is growing respect for brainstorming techniques as used by product design firms such as IDEO (Kelly & Littmann, 2001) and for structured invention processes using patent databases such as Theory of Inventive Problem Solving (TRIZ; Mann, 2002). Promising work on software tools includes studies of the Arrowsmith method of structured search in bibliographic databases to find indirect connections between two seemingly unrelated topics (Swanson, Smalheiser, & Torvik, in press).

During the past decade, respected psychologists who work on creativity, such as Mihaly Csikszentmihalyi (his books include the widely cited *Creativity*, 1996, and *Finding Flow*, 1997), have given a more compelling foundation. Csikszentmihalyi made two major contributions. First, his structured interviews with 91 creative people (Nobel and Pulitzer Prize winners, leading artists, corporate gurus, etc.) led to a thoughtful characterization of three key components for understanding creativity:

1. *Domain* (e.g., mathematics or biology) "consists of a set of symbols, rules and procedures."
2. *Field:* "The individuals who act as gatekeepers to the domain … decide whether a new idea, performance, or product should be included."
3. *Individual:* Creativity is "when a person … has a new idea or sees a new pattern and when this novelty is selected by the appropriate field for inclusion in the relevant domain."

This characterization focuses on the individual but clearly makes creativity a social process (Fischer, 2005; Fischer, Giaccardi, Eden, Sugimoto, & Ye, 2005), as an individual's work is recognized as creative only when judged by others. Csikszentmihalyi's second contribution was the development of the concept of *flow,* which is a state of mind in which an individual is performing skilled work at an appropriate level of challenge between anxiety and boredom. Individuals in the flow state are focused on their task and moving toward their goal, often with little awareness of their surroundings. They are less aware of time, often spending hours deeply engaged in their challenge. Although flow is not directly tied to creativity, many people engaged in creative tasks report being in such a flow state.

Robert Sternberg's (1999) remarkable edited collection, the *Handbook of Creativity,* has drawn popular and academic interest. The *Handbook* and numerous other books provide useful intellectual foundations concerning motivations, strategies, and assessment for human creative work. A particularly appealing chapter by Nickerson (1999) offered 12 steps to teaching creativity:

- Establish purpose and intention
- Build basic skills
- Encourage acquisition of domain-specific knowledge
- Stimulate and reward curiosity and exploration
- Build motivation
- Encourage confidence and risk taking
- Focus on mastery and self-competition
- Promote supportable beliefs
- Provide balance
- Provide opportunities for choice and discovery
- Develop self-management (metacognitive skills)
- Teach techniques and strategies for facilitating creative performance

Although Nickerson wrote from the perspective of teacher, these steps provide an excellent framework for learners who are striving to become more creative.

All of these discussions of creative individuals, groups, processes, and product are helpful, but we propose to push forward by focusing on creativity support tools that promote, accelerate, and facilitate creativity. Just as Galileo and Thomas Jefferson employed telescope and pantograph, contemporary innovators use computer-based software tools. We see compelling opportunities for dramatic improvements of tools for work in the sciences, engineering, design, medicine, humanities, arts, and beyond (Shneiderman, 2000, 2002). Recognized successful directions include search tools that enable people to more reliably find previous work and relevant knowledge. The current generation of tools has already changed the way many people work, but further improvements are expected, especially in exploratory search. Scientific, information, and data visualization software continue to be topics of intense development, so broader dissemination of these tools is possible. Visual brainstorming tools such as concept-mapping software are popular, and there is a growing family of visual presentation tools that push beyond slide presentation software to enable users to make compelling and even animated presentation of results.

Because many descriptions of creativity focus on the individual, it is important to balance this view with an appreciation of the importance of supporting creativity in small teams and larger communities (Bennis & Biederman, 1997). Scientific papers in mature fields such as physics and biology often have teams consisting of dozens of authors from multiple disciplines who contribute to a research result. Collaboration tools and the concepts of collaboratories are still expanding rapidly and were seen as productive research directions.

Creativity was rightly recognized as a key to economic growth and social transformation in the well-documented analysis by Richard Florida (2002), *The Rise of the Creative Class and How It's Transforming Work, Leisure, Community and Everyday Life*. His later work, *The Flight of the Creative Class* (2005), made the case even stronger, positing a global future shaped by communities that lure creative people by emphasizing the 3 T's: technology, talent and tolerance. If Florida's thesis is valid, then developing technologies that support and amplify creative talents could have a massive impact. Just as physicists were lured to facilities that provided powerful synchrotrons and astronomers came to work where the best telescopes were available, future creativity support tools will entice the most innovative minds and enable them to accelerate the pace of discovery and innovation.

Awareness of the benefits of focusing on creativity comes from the National Academy of Sciences (2003) report, *Beyond Productivity: Information Technology, Innovation and Creativity,* which argued that the challenge for the 21st century is to "work smarter, not harder." This report and others have identified the impact of creativity support tools on global competitiveness, successful civic infrastructures, scientific leadership, and educated citizenry. Outside the United States, national research agencies in England, Japan, Brazil, and other countries, are already supporting research projects that help develop creative industries, bridge science and art, and apply technology for innovative social processes.

Some commentators believe that creativity is the domain of the rare individual who arises only a few times in each century. This older notion celebrates historic figures such as Newton, Einstein, and Edison, but newer thinking proposes that every person can become more creative. In *Democratizing Innovation*, Eric von Hippel (2005) argued that "users of products and services—both firms and individuals—are increasingly able to innovate for themselves" (p. 1). He focused on manufacturing and product development, but the capacity of individuals to be creative grows as the software tools spread to diverse disciplines. Only a few inventors might have persisted, as Edison did, in trying 4,000 filaments for light bulbs, but modern software tools enable users to try thousands of variations on products in minutes.

The first generation of business software such as spreadsheets, database management, e-mail, and Web services changed the face of industry and created a global marketplace. The impact of improved domain-specific software tools is also clearly visible in filmmaking, digital photography, video editing, and music composition.

General purpose creativity tools are widely sold to support brainstorming in group discussion, idea formation based on thesauri, and knowledge elicitation with concept maps. However, these products are often promoted merely on testimonials, with little scientific study. Because the next generation of these tools is likely to have an even stronger impact as the number of users grows from few million to a few billion, rigorous evaluation is important to understand their benefits and limitations.

3. WORKSHOP GOALS

In assembling a group of leading researchers and graduate students, we sought to create a new community of interest around creativity support tools for individuals, teams, and communities. We believed the workshop on creativity support tools could do the following:

1. Accelerate the process of disciplinary convergence: Creativity support tool research must bridge multiple disciplines including computer science, psychology, human–computer interaction (HCI), information systems, information visualization, and software engineering. Researchers from one discipline may not appreciate the relevance of and rarely reference outside their discipline, thereby failing to take advantage of progress already made by others. Promoting awareness of interdisciplinary work would accelerate progress for all and improve quality.

Developing an understanding of how work in one discipline is useful to another would help advance the research process. A natural task is to reframe computer science research on user interface building tools and on collaboration technology as contributions to creativity support.

2. Promote rigorous research methods: The commercial promoters of current creativity support tools emphasize testimonials rather than research results. Attempts to apply controlled experimentation have been only marginally successful, because lablike settings and toylike tasks are fundamentally at odds with the goals of creative thinking. Rigorous research methods in creativity research will have to be developed because insight, discovery, and innovation are so difficult to assess. Researchers will benefit from development of appropriate benchmark tasks,

replicable evaluation methods, and respected strategies for in-depth longitudinal ethnographic studies.

3. Increase the ambitiousness of research programs: Creativity support researchers have proposed theoretical frameworks and innovative ideas that are slowly being refined through testing with small groups of users. With increased funding these projects could grow and researchers could grapple with more significant design issues. Also establishing an effective community of researchers will enable more extensive collaborations and support larger scale projects over longer time periods.

We believed that existing principles could be refined and applied to improve many software tools and design environments. Such tools are one of computer science's most fruitful contributions, amplifying the skills of millions of users through word processors, e-mail, Web browsers, spreadsheets, and graphics programs. Current tools are merely the first generation, which now can be enhanced with richer creativity support features.

4. CREATIVITY SUPPORT TOOL EVALUATION METHODS

The research findings reported in Sternberg's (1999) *Handbook of Creativity*, especially the chapter by Mayer, portrayed a broad field of research with multiple dimensions. This implies that there is a huge space of research projects that could focus on individuals, groups, products, or processes. Another dilemma in conducting research is that creativity may involve domain specific characteristics, but there are also domain independent phenomena as well. Some skills associated with being creative apply across a variety of domains, but sometimes extensive domain knowledge and abilities are needed—for example, the physical skills required by sculpting are different than those required by composition of music. Among the many remaining challenges is that creativity can vary quantitatively and qualitatively. For example, individuals may have varying amounts of creativity (e.g., as measured by psychometric tests), whereas different people may display different types of creativity (Gardner, 1993).

Acknowledging the multidimensionality of creativity is a necessary starting point, but the focus of our group was to evaluate the efficacy of creativity support tools as they affect individuals, groups, products, and processes. Because there is a legitimate argument that computers can interfere with creativity, interface and software designers need accepted methods to determine if novel tools promote or disrupt creativity.

Although controlled experimentation has long been seen as the leading approach to rigorous research in many areas of psychology and HCI, there was little sympathy for such methods in our workshop discussions. Controlled studies in laboratory conditions with standard or "toy" problems over a few hours were seen as inadequate to capture the strategy changes, new possibilities, and learning effects with powerful software tools, as they are applied to complex problems. More sympathy was expressed for in-depth longitudinal case studies and ethnographic field study methods to capture the rich texture of activity among creative individuals or groups (Csikszentmihalyi, Rathunde, & Whalen, 1993).

Because quantitative metrics of product quality or creativity are also difficult to apply, observation and interaction with creative individuals and groups over weeks or months was seen as necessary (Candy & Edmonds, 1997). These research methods can be made more rigorous by applying standard yet focused interview and survey questions across a range of individuals. Researchers have to hone their skills with multiple projects so that they become proficient in identifying creative work and the role of specific features in a creativity support tool. Researchers need to take care to recognize when a productivity support feature becomes so effective that it does more than merely speed performance of standard tasks, enabling freer exploration of alternatives and a willingness to probe past limits imposed by existing tools. Researchers also need to distinguish between software features that are merely novel and those that are demonstrably effective in enabling users to produce creative outcomes.

The group agreed that no single study, no single method, and no single metric was adequate in isolation but that convincing converging research results could emerge when multiple methods and multiple converging metrics were used over long periods of study—weeks, months, and sometimes years. Measures could be refined over time to include number, quality, and diversity of work products as well as reactions from informed colleagues about work products. Such reactions can be qualitative as in verbal or written comments, often with enthusiastic remarks and telling examples. Quantifiable reactions can also be through influences on other work—for example, creative scientific papers often, but not always, inspire more citations, innovative patents generate more licenses, and novel software results in more downloads or sales. Impressive examples of such multidimensional research was presented for studies of improved drawing tools for graphic artists and designers (Terry & Mynatt, 2002; Terry, Mynatt, Nakakoji, & Yamamoto, 2004) and for studies of collaboration in using group decision support tools (Fjermestad & Hiltz, 2000; Dennis, Nunamaker, & Vogel, 1990–91; George, Nunamaker, & Valacich, 1992; Vogel & Nunamaker, 1990).

Future researchers would do well to clarify which issues in the huge space of creativity they are addressing. Then it may take months of pilot testing to develop research strategies, followed by years to come to significant conclusions. A helpful analogy might be to pharmaceutical drug trials. Baseline measurements and standard practices have been refined over decades, but when a new drug is proposed the protocols are lengthy. Although some clinical trials may begin with small sets of patients, reliable assessments, clear understanding of the biological processes, and determination of side effects can take several years and involve dozens of researchers with thousands of patients. Major pharmaceutical advances justify the effort; similarly the high payoff from dramatically improved creativity support tools for engineers, scientists, designers, and others also justifies substantial effort.

In summary, the way forward focused on MILCs that used multiple metrics and evaluation techniques based on long-term in-depth observations and interviews over weeks and months with individuals and groups.

5. DESIGN PRINCIPLES FOR TOOLS TO SUPPORT CREATIVE THINKING

We have developed a set of "design principles," sometimes called *patterns*, to guide the development of new creativity support tools. We focus especially on composition tools, that is, computational systems and environments that people can use to generate, modify, interact and play with, and/or share artifacts such as programs, diagrams, designs, texts, images, and music. Many of these principles also apply to visualization, exploration, and discovery tools. These principles have emerged through collaborations with a large number of colleagues, in the development of many different creativity support tools, both for children and adults (Bederson, Grosjean, & Meyer, 2004; Hewett, 2005; Myers, Hudson, & Pausch, 2000; Resnick & Silverman, 2005; Selker, 2005; Shneiderman, 2000; Yamamoto & Nakakoji, 2005). Some of the principles are also relevant to tools for creating software in general, often called User Interface Software Tools, but targeting tools specifically for creativity highlights new perspectives and requirements.

A creative composition process is different from a routine production process that can be prescribed; therefore, the tools and representations people use strongly affect their courses of actions and thought processes. We recognize that these principles could be made more precise, clarified, and extended to cover special cases, but from experience we know that such compact sets of guidelines help to provoke discussion especially with those who will develop the next set of principles.

What distinguishes these principles from other user interface principles is that they emphasize easy exploration, rapid experimentation, and fortuitous combinations that lead to innovations.

1. Support exploration.
2. Low threshold, high ceiling, and wide walls.
3. Support many paths and many styles.
4. Support collaboration.
5. Support open interchange.
6. Make it as simple as possible—and maybe even simpler.
7. Choose black boxes carefully.
8. Invent things that you would want to use yourself.
9. Balance user suggestions with observation and participatory processes.
10. Iterate, iterate—then iterate again.
11. Design for designers.
12. Evaluate your tools.

The second principle was emphasized repeatedly, maybe because of its metaphoric quality: low threshold to enable easy entry for novices, high ceiling to enable experts to work on increasingly sophisticated projects, and wide walls to support a wide range of possible explorations. The third principle reminds designers that users will work in unpredictable ways that are likely to differ from what the designer anticipated. The fourth and fifth feature convenience in working with others. Principles 10 and 12 remind designers that their work is never done, because improvements are always possible.

Skeptics may challenge the need to propose design principles for creativity support tools when there are already many such tools available. Although there are certainly successful commercial products for programming environments, computer-assisted design or architecture, brainstorming, music composition, and so forth, we believe that many of these tools could be improved if designers applied the 12 principles. Improvements to tools could increase user productivity, but the key goal is to enhance user creativity.

6. WORKSHOP OUTCOMES

The lively discussions before, during, and after the workshop indicate that there are compelling issues for discussion. One participant made the memorable statement in his opening presentation: "I have been studying collaboration for 20 years but have only thought of creativity for two hours." Some of the spirit of the workshop discussion is captured in the seven issues that repeatedly emerged, such as the role of engagement, embodiment, and trust or the relationship between science, engineering, and new media arts (see full report at http://www.cs.umd.edu/hcil/CST).

Postworkshop comments by e-mail emphasized the fresh perspective, such as this comment from a respected senior researcher: "Absolutely the most stimulating meeting I have been to in a long time." Another participant wrote, "A magnificent effort to bring together such a diverse range of people and then have them align their research so well along a single axis." Finally, one of the graduate students commented, "Very stimulating and energizing. … I had trouble falling asleep … because my head was filled with new ideas. … I left with dozens of pages of notes to follow up on in my own research."

Maintaining such enthusiasm is difficult, especially in this community of active researchers who are engaged in multiple projects. Another challenge is the interdisciplinary nature of this work and the need for in-depth longitudinal case studies. Initiating new research directions is difficult, but the topic of creativity support tools could gain ground if there were acknowledgment for its importance among funding agency leaders. To serve that goal, we close this article with suggested directions, including the following:

- Evolve existing and develop new theories of creativity (incorporating social, technical, and organizational dimensions) grounded in a deep understanding of creativity.
- Identify the fundamental role of creativity in all disciplines (science, design, engineering, art, business, education, etc.).
- Propose radically new creativity support tools that facilitate and enhance creative thinking and creative expression.
- Design sociotechnical environments to support and enhance creativity.
- Formulate *systematic foundations* for widespread distribution of creativity support tools and their use in educational programs.
- Develop new assessment approaches (what should be measured and what can be measured), including differentiation between quantifiable and qualitative

dimensions; identification of qualitative dimensions such as personally meaningful activities, mindsets, relevance; evaluation techniques applicable to ill-defined, open-ended problems.

- Emphasize education and learning by doing with higher expectations that course projects result in innovative products and discoveries. Help students develop creative "habits of mind," for example, willingness to take risks and persevere when things go wrong.

Following the workshop, a number of relevant discussions have taken place, and here we briefly summarize some of the key points. Thinking about creativity, innovation, and discovery can influence many knowledge domains. One current proposal for "recentering" the discipline of computer science suggests that "the theme of innovation is central to the study of computing" (Denning & McGettrick, 2005, p. 17). As we discussed the workshop findings with others, we found a growing set of arenas in which creativity support tools are important. For example, although we had not considered safety critical systems as a target domain to start with, creativity is important in at least two aspects. First, before considerable effort is put into reliably implementing the specification of, for example, an aircraft's control system, designers need to be creative in ensuring that they have foreseen a wide range of scenarios and, hence, that the specification is as correct and complete as possible. Second, as such life-critical implementations are expensive, we need to be creative in finding the best methods for doing them.

Creativity is valuable in many stages of product design life cycles. One way to look at this is to look at the finances of product development in terms of commitment and the cost of change as against in terms of spend. It turns out that often a high commitment is made early on and the later cost of change escalates dramatically. Discovering a new idea or a problem with a planned development late in the day may be extremely frustrating. Encouraging creativity in the early stages, before too much is committed, can be effective both in terms of cost and quality.

Our discussions also returned to the recognition that measuring creativity is hard because creativity is such a complex subject. However, by bringing together objective measures, expert opinion, short experiments, and long-term case studies, we feel we are quite able to offer strategies to advance our ability to study and evaluate creativity support tools.

7. CONCLUSION

We seek to promote interest in creativity support tools by accelerating the process of disciplinary convergence. We aspire to bridge computer science, HCI, psychology, and related disciplines to encourage ambitious research projects that could yield potent tools for many people to use. We came to a consensus about these desirable future steps:

1. Accelerate research and education on creativity support tools by

    - Making the case for increased funding for creativity support tool research

- Encouraging investment in MILCs
- Proposing ways to create greater interest among researchers, educators, students, policymakers, and industrial developers

2. Promote rigorous multidimensional evaluation methods by

- Understanding the benefits and limits to controlled experimentation
- Developing observation strategies and metrics for in-depth longitudinal case studies
- Collecting careful field study, survey, and deep ethnographical data

3. Rethink user interfaces to support creativity by offering principles for

- Design tools for individuals and sociotechnical environments for groups
- Promote low floors, high ceilings, wide windows, and powerful history keeping
- Support exploratory search, visualization, collaboration, and composition

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APPENDIX A

Participants: Creativity Support Tools

Workshop Sponsored by the National Science Foundation
June 13–14, 2005, Washington, DC
Agenda at http://www.cs.umd.edu/hcil/CST/

National Science Foundation Program Manager

- Maria Zemankova

Organizers

- Ben Shneiderman, University of Maryland (Co-Chair)
- Gerhard Fischer, University of Colorado (Co-Chair)
- Mary Czerwinski, Microsoft Research
- Brad Myers, Carnegie Mellon University
- Mitch Resnick, MIT Media Lab

Participants

- Ernesto Arias, University of Colorado
- Hal Eden, University of Colorado
- Ernest Edmonds, University of Technology, Sydney, Australia
- Pelle Ehn, University of Malmö, Sweden
- Michael Eisenberg, University of Colorado
- John Gero, University of Sydney
- Elisa Giaccardi, University of Colorado
- Francois Guimbretiere, University of Maryland, College Park
- Tom Hewett, Drexel University
- Pamela Jennings, Carnegie Mellon University
- Andy Ko, Carnegie Mellon University
- Bill Kules, University of Maryland, College Park
- John Maeda, MIT Media Lab
- Kumiyo Nakakoji, University of Tokyo, Japan

- Jay Nunamaker, University of Arizona
- Gary Olson, University of Michigan
- Randy Pausch, Carnegie Mellon University
- Ted Selker, MIT Media Lab
- Elisabeth Sylvan, MIT Media Lab
- Michael Terry, Georgia Tech

Special invited speakers

- Peter Freeman, Assistant Director of the National Science Foundation for Computing and Information Science and Engineering
- Richard Florida, author of *The Flight of the Creative Class*; Professor, George Mason University

APPENDIX B

Report of Workshop on Creativity Support Tools

http://www.cs.umd.edu/hcil/CST/report.html
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Design Principles for Tools to Support Creative Thinking

- Mitch Resnick, Brad Myers, Randy Pausch, Kumiyo Nakakoji, Ben Shneiderman, Randy Pausch, Ted Selker, and Mike Eisenberg

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- Pamela Jennings and Elisa Giaccardi

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- William Kules

Funded Research Relevant to the Creativity Support Tools

- Ernest Edmonds

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- Kumiyo Nakakoji

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- Gerhard Fischer

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- Gerhard Fischer