Creativity Support Tools

A workshop sponsored by the National Science Foundation

June 13-14, 2005, Washington, DC

http://www.cs.umd.edu/hcil/CST

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

Report: September 2005

NSF Workshop Report on Creativity Support Tools
Participants List

Sponsored by the
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National Science Foundation Program Manager: Maria Zemankova

Organizers:

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The organizers greatly appreciate the:

- Enthusiasm and helpfulness of our National Science Foundation program manager, Maria Zemankova under Award 0527109
- Encouragment and support of Michael Pazzani (Division Director, Information and Intelligent Systems) and Peter Freeman (Assistant Director of the National Science Foundation for Computing and Information Science and Engineering (CISE))
- Diligent work of Cecilia Kullman in administering and arranging the workshop
- Capable efforts of Kiki Schneider in preparing the report for printing
- Creative work of Sabrina Liao in designing the cover
- Timely work of Adam Perer and Kiki Schneider in managing the web site.

NSF Workshop Report on Creativity Support Tools
Schedule

Monday June 13, 2005 (9:00am-5:00pm)

9:00am Introductions and Vision Statements
Ben Shneiderman and Gerhard Fischer

10:45am **Sequential Presentations on Current Research Directions**
Computer Science (A1): *Brad Myers & Randy Pausch*
Business & Information Systems (A2): *Jay Nunamaker*
Psychology (A3): *Mary Czerwinski & Tom Hewett*

12:15pm Lunch (Speaker: Peter Freeman, NSF)

1:45pm **Sequential Presentations on Current Research Directions**
Creative Practices (Art, Interaction Design, and Culture) (A4)
Elisa Giaccardi & Pelle Ehn

2:15pm **Parallel breakout sessions on selected topics to make a more complete list of current researchers, projects, products:**
Computer Science (B1)
Ernest Edmonds
Creative Practices (Art, Interaction Desigh, and Culture)(B2)
Pamela Jennings & Elisa Giaccardi
Psychology (B3)
Mary Czerwinski & Tom Hewett

7:00pm **Dinner**
Speaker: Richard Florida, *The Rise of the Creative Class* and
The Flight of the Creative Class

Tuesday June 14, 2005 (9:00am – 4:30pm)

9:00am **Sequential presentations on Current Research, Products, and Opportunities**
Information Visualization & Online Search (C1): *Ben Shneiderman & Bill Kules*
Collaboration Tools (C2): *Gary Olson*
Composition Tools (C3): *Mitch Resnick & Mike Eisenberg*

1:30pm **Parallel breakout sessions on selected three topics to make lists that:**
(1) describe the current state of research, projects, products
(2) identify future research directions
(3) propose ways to create greater interest among researchers, students, and industrial developers.

Information Visualization & Online Search (D1): *John Maeda*
Collaboration Tools (D2): *Ernesto Arias*
Composition Tools (D3): *John Gero & Kumiyo Nakakoji*

3:15pm Reassemble as a group to hear reports and discuss future directions
4:30pm Adjourn

NSF Workshop Report on Creativity Support Tools
Executive Summary

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 more productive, and more innovative. Potential users include software and other engineers, diverse scientists, product and graphic designers, architects, 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 (computer programs, scientific papers, engineering diagrams, symphonies, artwork), enhanced interfaces could facilitate exploration of alternatives, prevent unproductive choices, and enable easy backtracking.

This NSF-sponsored workshop brought together 25 research leaders and graduate students to share experiences, identify opportunities, and formulate research challenges. Prepared presentations in the mornings provided structured reviews of previous work, while open discussions in the afternoon encouraged broad participation and new directions. Two key outcomes emerged:

1) Formulation of guidelines for design of creativity support tools. Consensus grew about the necessity of *low thresholds* (easy entry to usage for novices), *high ceilings* (powerful facilities for sophisticated users), and *wide walls* (a small, well-chosen set of features that support a wide range of possibilities). The need for easy exploration of multiple alternatives ("Support many paths, many styles") and powerful history-keeping (convenient backtracking and undo) emerged repeatedly. Other guidelines are captured in the report.

2) Novel research methods to assess creativity support tools. The complexity of creativity was a recurrent theme, leading this subgroup to define a five-dimensional model for researchers, addressing issues such as process vs. product, individual vs. social, and domain-specific vs. domain independent. Workshop participants generally found narrow application for controlled experimental methods, and stressed the need for longitudinal and observational studies that tracked usage of powerful tools by individuals and groups over weeks, months, and years. A case study approach based on applied ethnographic research and participant observation with domain experts was stressed, but the need to complement such observations with other methods such as field studies, surveys, and deep ethnographies appeared repeatedly.

The workshop participants were eager to see a greater integration of creativity concepts in many projects and funding initiatives. By focusing on human creativity (processes, tools and products), novel and improved interfaces are likely to be proposed. By studying users of creativity support tools, refined understandings of how people create, cooperate, and discover are likely to emerge. Since creative innovations and discoveries have profound effects on science, engineering, work, and society, substantial and long-term research efforts can have high payoffs.

Primary beneficiaries of this research include software and other engineers, diverse scientists, product and graphic designers, architects, and other technical professionals. Secondary beneficiaries include music composers, playwrights, and other new media artists. Of course, creativity support tools would also help children and students learn to express themselves creatively -- and help them develop as creative thinkers.

In summary, the workshop participants converged on three highly desirable goals. We are eager to:

- **Accelerate research and education on creativity support tools by:**
    - Making the case for increased funding for creativity support tool research
    - Encouraging investment in substantial multi-year longitudinal case studies
    - Proposing ways to create greater interest among researchers, students, policymakers, and industrial developers.
    - Provide appropriate software infrastructure and toolkits so that creativity support tools can be more easily built.

- **Promote rigorous multidimensional evaluation methods by:**
    - Understanding the benefits and limits to controlled experimentation
    - Developing observation strategies for longitudinal case studies
    - Collecting careful field study, survey, and deep ethnographical data

- **Rethink user interfaces to support creativity by offering guidelines for:**
    - Design tools for individuals and socio-technical environments for groups.
    - Promote low thresholds, high ceilings, wide walls, and powerful history-keeping
    - Support exploratory search, visualization, collaboration, and composition

Introduction to Workshop Report

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

> *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.*

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 and microscopes of previous generations are giving way to advanced user interfaces on computer tools 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, open physics preprint archives, 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 socio-technical environments over longer time periods. Expectations are high and belief in beneficial outcomes is great, but much work remains to be done to develop a respected academic discipline with validated results.

Interest in creativity is growing. Computing companies, such as Hewlett-Packard feature ‘innovation’ as their expertise, while Intel and Microsoft present appealing television commercials that promise to empower young minds with technology (‘Your potential, Our passion’). Consulting companies claim expertise and software entrepreneurs promote products with little more than testimonial support. Websites 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, designers developing novel consumer products, or children in (and out of) classrooms. 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. Another lively source of ideas is from innovative educational environments for children and students. For each of these projects novel research methods could also accelerate our understanding of what software improvements are needed.

The workshop report includes two major sections that discuss research methods that are appropriate for studying creativity support tools and initial guidelines for the design of creativity support tools. The audience for this report includes research managers in government, industry, and universities, as well as researchers interested in exploring these new directions. Additional sections cover:

- the relationship to work of new media artists, indicating what can be learned from this community that strongly identifies with the notions of creative work products
- the role of search tools and information visualization
- a survey of efforts around the world related to creativity tools
- a set of seven issues discussed during the workshop
- a review of creativity and distributed intelligence
- a set of future research directions

The remainder of this introduction reviews current thinking about creativity and describes the workshop outcomes.

Current thinking about creativity

The potential for enhancing human creativity has been a recurring theme of visionary thinkers such as Edward DeBono whose 'lateral thinking' ideas have had a warm reception, internationally, but a cool reception from academics. Dan Couger's review of 22 creativity methods included the classic ones such as the methods described by Hadamard, reporting on Poincare: Preparation, incubation, illumination, verification. Recent variations, include these design steps for engineering (Adams et al., 2003, Atman et al., 2003):

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

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, since an individual's work becomes 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 towards their goal, often with little awareness of their surroundings. They are less aware of time, often spending hours deeply engaged in their challenge. While flow is not directly tied to creativity, many people engaged in creative tasks report being in such a flow state.

Robert Sternberg's remarkable edited collection, the *Handbook of Creativity* (1999), has drawn popular and academic interest. This *Handbook*, and numerous other books, provide useful intellectual foundations concerning motivations, strategies, and assessment for human creative work. A particularly appealing chapter by Nickerson offers 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 (Meta-Cognitive Skills)
- Teach Techniques and Strategies for Facilitating Creative Performance

All of these discussions of creativity are helpful, but we propose to push forward by focusing on creativity support *tools* that promote, accelerate, and facilitate creativity. Just as Galileo and 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, medicine, knowledge work, humanities, arts, and beyond.

Since 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. 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.

Creativity has been rightly recognized as a key to economic growth and social transformation in the well-document 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)

makes 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.

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, or Edison, but newer thinking proposes that every person can become creative. Eric von Hippel's *Democratizing Innovation* (2005) argues that "users of products and services -- both firms and individuals -- are increasingly able to innovate for themselves." He focuses on manufacturing and product development, but the capacity of individuals to be creative grows as the software tools spread to diverse disciplines. The first generation of business software such as spreadsheets, database management, email, and web services changed the face of industry and created a global marketplace. The impact of improved software tools is also clearly visible in filmmaking, digital photography, video editing, and music composition. The next generation of these tools will have an even stronger impact as the number of users grows dramatically from few million to a few billion people.

Awareness of the benefits of focusing on creativity comes from the National Academy of Sciences report *Beyond Productivity: Information Technology, Innovation and Creativity* (2003), which argues that the challenge for the 21st century is to "work smarter, not harder." This report and others identify the impact of creativity support tools on global competitiveness, successful civic infrastructures, scientific leadership, and educated citizenry.

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:

1) **Accelerate the process of disciplinary convergence:** Creativity support tool research must bridge multiple disciplines including computer science, psychology, human-computer interaction, 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 lab-like settings and toy-like tasks are fundamentally at odds with the goals of innovative thinking. Rigorous research methods in creativity research will have to be developed because insight, discovery, and innovation are so

difficult to asses. Researchers will benefit from development of appropriate benchmark tasks and replicable evaluation methods.

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.

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

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." Post workshop comments by email emphasized the fresh perspective, such as this comment from a respected senior researcher: "Absolutely the most stimulating meeting I have been to in 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." And 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 intense longitudinal case studies. Initiating new research directions is difficult, but the topic of creativity support tools could gain ground if there were acknowledgement for its importance among funding agency leaders.

The authors of this report 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 the outcome that would:

- **Accelerate research and education on creativity support tools by:**
    - Making the case for increased funding for creativity support tool research
    - Encouraging investment in substantial multi-year longitudinal case studies
    - Proposing ways to create greater interest among researchers, students, policymakers, and industrial developers.
    - Provide appropriate software infrastructure and toolkits so that creativity support tools can be more easily built.
    -
- **Promote rigorous multidimensional evaluation methods by:**
    - Understanding the benefits and limits to controlled experimentation

- Developing observation strategies for longitudinal case studies
- Collecting careful field study, survey, and deep ethnographical data

- **Rethink user interfaces to support creativity by offering guidelines for:**
    - Design tools for individuals and socio-technical environments for groups.
    - Promote low thresholds, high ceilings, wide walls, and powerful history-keeping
    - Support exploratory search, visualization, collaboration, and composition

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Creativity Support Tool Evaluation Methods and Metrics

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Mary Czerwinski, Microsoft
Michael Terry, Georgia Tech
Jay Nunamaker, University of Arizona
Linda Candy, University of Technology, Sydney
Bill Kules, University of Maryland
Elisabeth Sylvan, MIT

An overview and meta-analysis of psychological research on creativity

One goal of this portion of the report is to provide a brief overview of our current understanding of what the psychological research community examining creativity tells us about the topic, as well as to review some of the conceptual and methodological issues involved in the psychological study of creativity. A third goal is to discuss some of the implications of this research for requirements analysis for creativity support tools, for the design of creativity support tools, and for the evaluation of the impact of those tools intended to support creativity. This discussion is based upon a presentation and subsequent discussion at the NSF Sponsored Creativity Support Tools (CST) Workshop held in Washington, DC in June of 2005.

In providing an overview of the Psychological research on creativity we have relied heavily on various sources in The Handbook of Creativity (Sternberg, 1999), in particular the overview article by Mayer (1999). The authors in Sternberg's collection of reviews provide a high level view of the state of the art and findings of psychological research on creativity. The work in this Handbook is highly consistent with the work of several other authors who have also surveyed major aspects of the research findings (e.g., Csikszentmihalyi, 1997; Gardner, 1989).

Several of the authors in Sternberg adopt a working definition of creativity that is consistent with those offered by other authors and that involves several key components. Basically, creativity can be considered to be the development of a novel product that has some value to the individual and to a social group. However, it seems that the research conducted by psychologists on creativity does not allow us to clarify or simplify this definition any further. Different authors may provide a slightly different emphasis in their definition but most (if not all) include such notions as novelty and value. For example, Gardner (1989) emphasizes that creativity is a human capacity but includes novelty and social value in his definition. An important thinker and researcher on creativity, Csikszentmihalyi (1997), emphasizes that creativity involves process but stipulates that that process can be observed only where individuals, knowledge domains, and fields or social groups intersect.

In summarizing the research findings reported in the various chapters in Sternberg(1999) it is clear that that there are several diversities (Mayer, 1999) that can be thought of as being underlying dimensions to creativity and the study of creativity. For example, one dimension is that creativity can be a property of people, a property of products, and a property of a set of cognitive processes. This diversity leads to a concern with individual differences between people. It also leads to a concern with the properties of a product that make it novel and valuable. Finally, it leads to a concern with analyzing the steps and processes of thinking which are associated with production of a creative result.

A second dimension of creativity and in creativity research to be found in various chapters in Sternberg (1999) is that creativity can be thought of as a personal and a social, societal or cultural phenomenon. At an individual level creativity is said to involve the development of something novel and valuable to the individual. At the social level it involves a creation that adds something new to the culture. This dimension parallels the distinction made by Boden (1990) between P-creative and H-creative. Boden's important conceptual clarification helps advance the discussion of creativity as it then becomes clear that an individual may be personally creative in coming up with something novel to themselves (P-creative), without necessarily being H-creative by making a contribution to the human race.

A third dimension in creativity research and to creativity to be found in Sternberg (1999) is that creativity can be thought of as being common or frequent, or it can be thought of as being rare. Effectively, some aspects of the research on creativity suggest all humans are potentially capable of creativity (in Boden's P-creative sense). Alternatively the research suggests that major creative works (in Boden's H-creative sense) are rare.

Another dimension of creativity to be found in the literature on creativity research discussed in Sternberg (1999) is that creativity may involve domain specific characteristics but that there are also domain independent or general phenomena as well. In other words, there appear to be general skills associated with being creative that apply across a variety of situations or domains of knowledge and/or practice. On the other hand it seems that different domains require extensive domain knowledge and domain specific special abilities (e.g., the physical skills required by sculpting are different than those required by composition of music).

The fifth dimension of creativity research and creativity to be found in Sternberg (1999) is that creativity can be seen as being quantitative or it may be seen as being qualitative. For example, individuals may have varying amounts of creativity (e.g., as measured by psychometric tests). Furthermore different people may display different types of creativity (cf., Gardner, 1986).

Yet another dimension of creativity and in creativity research to be found in Sternberg (1999) is that creativity can be individual or it can be social, in the sense of a group of people working together. For example, it is possible to study how individuals may be creative or produce a creative result. Similarly, groups of people working together may also produce a creative result that is a group result and that is not uniquely the product of a single member of the group. Thus it becomes necessary to study social entities, social products and social processes to fully understand creativity.

Recognition of the fact that there are multiple dimensions to creativity and in creativity research, leads us to propose that these various aspects of creativity research and creativity should be thought of as being different dimensions of a taxonomy for creativity studies and creativity support tools. In other words, the problem of developing Creativity Support Tools is one in which one must first decide in which intersection of the n-dimensional taxonomy one wishes to study and work.

For example, a Creativity Support Tool might be designed to support group work either by focusing on facilitating processes through to enhance creativity or by enabling the production of a physical artifact that is both novel and useful. This tool might not be of any use at all to an individual. While it is clear that not all possible permutations of this n-dimensional taxonomy have been explored, it does seem safe to argue that it should be possible clarify future discussions of Creativity Support Tools if investigators make use of such a Taxonomy to clearly stipulate which particular intersection of factors best characterizes the goals and nature of the Creativity Support Tool upon which they are working. This specification would also be of assistance in deciding upon which methodologies and metrics should be used in assessing the degree to which a Creativity Support Tool is thought to facilitate creative work.

An over view and meta-analysis of research methods used to study creativity

Mayer (1999) provides a review and some observations on a variety of behavioral science research methods used to study creativity. Specifically he discusses psychometric methods, experimental methods, biographical methods, biological methods, computational methods and contextual methods. In addition he addresses some of the strengths and weaknesses of these various methods, making the important point that in studying creativity one should use more than one methodology to allow one to compensate for the weakness of a single methodology. This can be done by bringing to bear the strength of another methodology and is based upon the assumption that the two different sets of weaknesses can effectively cancel each other out. The goal of this section of the report is to summarize, and, in a few cases, comment on Mayer's observations. It should be also noted that this idea of use of multiple converging methods and metrics for studying creativity and creativity support tools motivated much of a breakout group discussion described below.

The first set of research methods addressed by Mayer is the Psychometric method. This collection of procedures involves the development of various psychological tests that are intended to assess various traits or characteristics of creative people. The strength of this method, Mayer argues, is the fact that it has a long history and the procedures for developing such tests are well established. The major weakness of the Psychometric method, however, is basically that such tests, e.g., tests of divergent thinking, don't seem to predict creative thinking. Another way of thinking about this weakness is that Psychometric tests lack predictive validity, criterion validity and discriminant validity. That is, they don't seem to offer a strong way of allowing us to identify who will be creative, what results will be accepted as creative, or allow us to distinguish between creative and non-creative people.

The fundamental nature of the problem here can be understood by noting that even if one has a significant correlation between the pencil and paper test and some other indicator of creativity, the real power of a relationship between two variables lies not in a statistically significant correlation but in the percentage of variance accounted for by the relationship. If one takes the square of the correlation coefficient one has then calculated the percentage of variance accounted for by knowing the score on one variable when trying to predict a value on the other. Thus a significant correlation of 0.5 only accounts for 0.25% of the variability in the score on the other variable.

Mayer (1999) describes experimental methodologies as having the inherent strength of all laboratory research. The control one exercises increases the validity or strength of one's conclusions. (Effectively, in a well controlled experiment the researcher has only two possible explanations for the result of a manipulation. Either the result is an effect of the manipulation or it has occurred by chance. Careful selection of a level of statistical significance allows one to estimate the possibility of a chance result.) Not surprisingly, the weakness of experimental methods identified by Mayer is that with increased control comes reduced generalizability of one's conclusions. This is a long standing and well understood problem with experimental research which has been grappled with in a variety of ways (e.g., Campbell & Stanley, 1966; Cook & Campbell, 1979; Webb et al, 1969; Webb et al, 1981). One important implication of this inescapable trade-off between control and generalizability is that laboratory definitions of "creativity" are often so tightly constrained that they do not capture more than a piece of a person, product or process. And that piece is usually observed outside of a natural context.

Turning to biographical methodologies, Mayer notes that their strengths derive from the fact that carefully documented histories can provide both detail and a feeling of authenticity. However, not all histories are carefully documented at the time events are taking place. Furthermore, there are potential biases introduced as a result of a focus on a small set of pre-selected people. Both of these problems raise the concern that one may have access to only part of the data to work with or that the reporting of events may

be influenced to some degree by selective memory. For example, autobiographical accounts composed years after the fact may talk only about successes and may omit or downplay failures, etc.

In recent years a whole new collection of biological methodologies have become available, and as Mayer points out, brain event recording data provides information not available to other methodologies. The down side he notes is that it is not clear yet how cognitive activity can be reduced to brain activity or vice versa. We interpret this to mean that reports of brain behavior correlates provide us with some new information but as yet it is not clear that this will lead to any new understanding of the phenomena of creativity.

Another relatively recent set of methodologies for the study of creativity involves computational modeling. In computational modeling one instantiates a theory in the form of a computer executable program that is thought to incorporate the same types of constraints and limitations as found in human cognition. Mayer points out that these modeling efforts allow for a rare level of precision which allows for objective testing via simulation. The weaknesses he identifies include the observation that it is not clear that such modeling will ever have a broad enough scope to deal with the full range of phenomena of interest.

In addition Mayer (1999) claims that computational modeling assumes that cognition can be reduced to mathematics. On this point we tend to disagree with Mayer for several reasons. First it is quite possible to use a digital computer to simulate certain analog processes and produce output that simulates and is indistinguishable from an analog device. Second, it is quite possible to use a digital computer with a single CPU that processes events in serial order to simulate certain parallel processes and produce output that is indistinguishable from a parallel device. Finally, there appears to be no a priori reason why a digital computer can not simulate cognitive events and processes in such a way that it produces output which is indistinguishable from the human. The fact that a mathematically based device is used to simulate another device does not entail the second device is thought to be reducible to mathematics, only that mathematics can be used to model it.

The final set of methodologies for the study of creativity discussed by Mayer (1999) are contextual methodologies. The strength of these methodologies lies in the fact that they place the study of creativity in a personal, social, societal, cultural and even an evolutionary context. The projects studied are defined by the practitioner and the research studies creativity using research based in actual practice. The weakness of these methodologies identified by Mayer is the shortage of data and of testable theories based on such studies. Another weakness of these methodologies is related to the sources of strength and weakness discussed in experimental methodologies. The further one moves away from the controlled laboratory situation the more difficult it becomes to establish a clear unambiguous set of relationships that support valid conclusions. Research based in actual practice often supports many alternative explanations of what happens and how it happens.

Is creativity enhancement actually a reasonable goal?

All of the complexities one encounters in trying to study creativity, e.g., deciding upon which part of the n-dimensional space one wishes to explore and then deciding upon the appropriate methodologies and metrics to employ, reveal the rich set of design issues that developers of creativity support tools face. The psychological literature provides no clear, unequivocal answer to whether or not creativity can be enhanced. There are many different variables that have been proposed as having a role, including individual abilities, interests, attitudes, motivation, intelligence, knowledge, skills, beliefs, values and cognitive styles. Thus it seems that individual, social, societal and cultural differences and factors may all matter, at some time or another and under some circumstance or another.

Despite all these complexities, there is some hope. As Hewett (in press) has argued, we may not yet understand enough about the conditions under which creativity is going to happen to be able to help it along, but we do understand some of the things that make it harder for creativity to happen. Knowing what disrupts creativity makes it possible to figure out ways of staying out of the way and not interfering. Furthermore, Nickerson (1999) and Csikszentmihalyi (1997) have provided useful evidence suggesting that there are techniques useful in teaching and/or enhancing personal creativity. Both of these authors show strong convergence in their conclusions. Furthermore many of the techniques identified by Nickerson that may be useful in teaching creativity can also be applied as personal improvement techniques. A list of factors involved include such things as: Establish the purpose and intention of being creative; 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; Provide opportunities for choice and discovery; and Develop self-management (meta-cognitive) skills.

Does this list of strategies for teaching or improving personal creativity have implications for design and development of Creativity Support Tools? The answer appears to be "yes." As pointed out by Linda Candy (personal communication) there are three clear HCI objectives implied by what we do know. The first objective is to enhance the personal experience of the person who wants to be creative. The second is to look for ways to improve the outcomes and artifacts. The third objective is to support the improvement of process by providing tools that are designed with certain functional requirements in mind.

The types of functional requirements and or design criteria which should be useful have been articulated in a series of papers by Candy and Edmonds (1994, 1995, 1996, 1997) and further extended and explored by Hewett (in press). For example, any Creativity Support Tool should allow the user: to take an holistic view of the source data or raw material with which they work; to suspend judgment on any matter at any time and be able to return to that suspended state easily; to be able to make unplanned deviations; return to old ideas and goals, formulate, as well as solve, problems; and to re-formulate the problem space as their understanding of the domain or state of the problem changes.

Breakout group report on Evaluation of CST

After a series of presentations earlier in the workshop a group of people concerned particularly with the problems of appropriate methodologies and metrics for assessing the impact of computer-based tools intended for creativity support met to discuss some of the issues raised by the workshop presenters. Not surprisingly, with very little discussion the group found they shared an overriding belief in a fundamental principle of evaluation of support tools. Basically this principle states that there is a FAMILY of evaluation techniques which must be brought to bear in order to CONVERGE on the key issues involved in the study of Creativity Support Tools.

The reasons for this principle lie in the fact that any research methodology will inherently have some fundamental assumptions and/or flaws which may make it inappropriate as a single tool for a thorough, meaningful interpretation of a result. For example, evaluation techniques range from lab-based, controlled studies (perhaps only possible when you know an area well or it is mature, or when the area is extremely new) to field studies (performed early on to understand the problems and the corresponding scope) to surveys (which have only limited value) and deep ethnographies (which are powerful methods for understanding user behavior and generating hypotheses).

The group also agreed upon an important corollary of the principle that multiple methods are required for

assessing different aspects or different people, processes, or products involved in creative work, i.e., converging lines of evidence are needed. This corollary is that no single metric or measurement technique is without assumptions and inherent error of measurement. Thus various measurement techniques must, wherever possible, be combined with other metrics or measurement techniques in ways that the different measure converge upon an answer to the question(s) being asked in evaluation. The additional complexity raised by consideration of the need for multiple evaluation methods and multiple evaluation measures was that no single method or measure will be appropriate for all situations or all aspects of the complex phenomenon of creativity.

That being said, the breakout group turned its attention to generating examples of the types of questions that should be asked in evaluation studies of Creativity Support Tools (recognizing that the list is not exhaustive and that not all questions would be addressed in a single study). The list of questions generated by the group includes:

Example/sample questions to be asked in evaluation:

Is this technique better than existing practice?
Does it expand its use to other contexts?
Have you learned how to improve this tool based on this evaluation?
How does the tool/technique influence the creative process?
What facets of creativity are affected? To what degree?
How brittle is the tool/technique? How accepted is it by the users over the long term?
Does it celebrate diversity?
How does this method complement others in the family of tools/techniques?
What is the task-to-technology "fit"?

The next aspect of the breakout group's discussion involved producing examples of possible metrics and measures that might be used to answer one or more of these questions. Recognizing that this list is neither exhaustive and that not all of these metrics and measures would be appropriate in all evaluation studies, the list generated by the breakout group consisted of the following:

Sample measures and metrics to be used in an evaluation:

#of unique alternatives attempted
Degree of radicalism/conservatism if alternatives attempted
Value of solutions attempted (to whom?)
Quality of solutions (Gary Olsen has developed expert-derived scale based on what it is you are creating)
Side Effects: serendipitous solutions
Time to come up with solutions
Satisfaction with solutions
Progress if there is a deadline imposed
Tradeoffs or "cost-benefit" analyses of cognitive resources applied or allocated to solutions v. those freed by alternative techniques (the last two or three can be applied "socially" as well as individually)
Organizational agility
# of Person Hours required for satisfactory solution
# of people supported by the tool/process
Cultural appropriateness of the tool/process
People's subsequent buy-in of the tool/process
Ease of learning and remembering

# of errors made through the user interface while using the tool/process

In the final stages of discussion the breakout group turned to looking at some of the case study examples presented during the workshop or discussed during this breakout session (with thanks to Michael Terry, Gary Olson and Jay Nunnamaker). Beyond the superficial generalization that creativity support is difficult, and evaluation of its success is complex, it was possible to summarize some important general lessons from these presentations.

Commentary on the Breakout group report.

Reflection on the breakout group discussion and the case study examples discussed there basically provides a set of guidelines for planning and conducting the process of developing and evaluating a Creativity Support Tool.

Step 1: First it is necessary to observe the activities and problems users are having in real time, either through field/ethnographic research, computer logging, or via actual participatory design.

Step 2: Next the researcher must gather user requirements for design of a system that solves real user problems or assists them in activities that they need to perform.

Step 3: Design and implement a solution. (This can often be done quickly and inexpensively using low fidelity prototypes.)

Step 4: Iterate via a series of evaluation studies that might start out qualitatively but end up being quantitatively examining new tools versus existing practice.

Step 5: Repeat Steps 3 and 4 as often as needed.

Step 6: Finally, follow up with the end system out in the field longitudinally, with users using the tools to do their real work in real time over an extended period of time.

Table 1 summarizes the techniques, what they are good for, and advantages and disadvantages.

Technique	Good For	Advantages	Disadvantages
Controlled study	For specific questions and when you know an area is ripe for improvements.	Rigorous.	Time consuming. Low external validity.
Field Study	Early on to understand the problems and the corresponding scope		
Survey	A quick overview or description of a phenomenon.	Quick, easy to administer and analyze.	Limited value. Self-report.
Deep ethnography	when you have no idea about the real problems to solve or what a very deep understanding of an area		Most time-consuming

Table 1. Various research methods for studying creativity and their pros and cons.

For some additional sources of information on several of the ideas expressed here see the case study descriptions provided below and the papers by Campbell & Fiske (1959) and Hewett (1986).

When the breakout group report was circulated for comment there were some very useful elaborations suggested. For instance, it was thought that Step 1 above is particularly important and challenging -- and in the context of creativity research may be more so than in other domains. Many creativity tasks are loosely defined at best. The strategies and tactics that people who are working creatively bring to a task are situation-specific and often ideosyncratic. Users may apply tacit knowledge and have difficulty articulating the task without performing it. This makes step 1 especially important. In other domains, where activities are more formalized, you can often collect valid requirements even if you skip or minimize step 1, but that is likely to be riskier for creativity support tools. For similar reasons, during step 1 it is especially important to "tease out" higher-level thinking that occurs. Log studies can contribute, but they can't replace research that listens to users, asks "why," and seeks to understand what they are thinking (while recognizing that any findings are unlikely to be comprehensive). Other main concerns included: what are the issues in understanding creativity support tools, as opposed to other tools, and how do we create measurement techniques that ask whether the tool supports creativity, rather than, say, innovation or productivity?

An example of using multiple methods and metrics for study of creativity.

Creativity is a socially defined activity (Csikszentmihalyi, 1997). As such, measures of a creativity support tool's success are partially dependent on how success is defined and evaluated within a specific community of practice. Consequently, traditional measures such as performance or efficiency, while still important, are only one lens with which to view the value of a creativity support tool. To gain a more holistic perspective of how a tool influences the creative process, one may find it necessary to define new ways of measuring the impact of a creativity support tool on the problem solving process, where these metrics are derived from practices deemed important by the community under investigation.

In this section, we use research by Terry and Mynatt and their associates (2002a, 2002b; Terry, Mynatt, Nakakoji & Yamamoto, 2004) as a case example study to illustrate how a deep understanding of a community of practice can not only inform tool design, but can guide subsequent evaluations. This case study highlights the importance of employing mixed methods for evaluation, and argues that a richer suite of evaluation instruments is necessary to study creativity support tools.

Understanding User Needs

If one optimizes current practices (that is, *what* people do), one can expect only incremental improvements in computer-based support for the creative process. On the other hand, understanding *why* people do what they do can lead to new insights into the forms computational support can take. These data also indicate how one should judge the success of any computational tool support developed. Thus, before the design and evaluation of creativity support tools can commence, one should have a clear idea of the needs of a group of individuals, as well as an understanding of why these needs exist.

Among the many tools at a researcher's disposal, qualitative methods (e.g., ethnography, field studies, and the like) are particularly well-suited to gaining a deep understanding of the needs and methods of a community of practice. When performed by an experienced researcher, in-situ observations and semi-structured interviews can yield a rich set of data in a relatively short period of time (Millan, 2000), providing the information necessary for subsequent design and evaluation phases.

In studying the practices of graphic artists and designers, Terry and Mynatt (2002a) used field studies and semi-structured interviews to investigate how computational tools could better support day-to-day work processes in the visual arts. Their research uncovered one particular practice that seemed poorly supported by current interfaces: Generating and comparing multiple ways of solving a problem. Creating sets of alternative solutions is a common practice that serves many purposes when solving ill-defined problems (Terry, Mynatt, Nakakoji & Yamamoto, 2004; Newman & Landay, 2000). For example, it allows the researcher to make concrete comparisons between multiple solution possibilities. It can also force the user to push beyond current approaches to seek out more novel ways of solving a problem. However, despite its importance, Terry and Mynatt's studies found that current interfaces tend to lead to highly linear problem solving methods by virtue of offering few tools to facilitate exploration. These data led to the following hypotheses:

- Current interfaces lead to highly linear problem solving processes
- Tools that enable one to more easily explore and compare alternative scenarios would yield better solutions, faster
- Users would prefer tools that enable them to more easily explore

These hypotheses outlined the design space for computational tools, but also indicated deficiencies in evaluation instruments. In particular, concepts such as "breadth of exploration," while intuitively understood, do not have precise definitions. Thus, measures of success relevant to this community, such as broad exploration, needed to be qualified to enable the measurement of this phenomenon.

Evaluating Exploration

The field studies of graphic artists and designers led to the design and implementation of two tools, Side Views and Parallel Pies, both for use in Photoshop-like image manipulation applications. Side Views (Terry & Mynatt, 2002b) automatically generates sets of previews for one or more commands and their parameters, allowing one to quickly generate sets of potential future states that can be compared side-by-side. Parallel Pies (Terry, Mynatt, Nakakoji & Yamamoto, 2004), on the other hand, streamlines the process of forking and creating sets of separate, standalone solution alternatives.

To understand the impact of their tools on the problem solving process, Terry and Mynatt employed three different studies: two controlled laboratory studies, and a third, think-aloud study. These studies differed by task type and the data collected to provide a more holistic understanding of how these tools affect various aspects of the creative process. We summarize each in turn.

The first study asked individuals to color-correct an image to make it match a known (visible) goal state. While highly artificial (since the goal was known), the task nonetheless had an ill-defined solution path. Furthermore, the known goal state allowed the researchers to algorithmically measure *how close* the subjects got to achieving the goal. This study's design, then, provided a baseline for how well subjects could perform when they knew exactly what they were looking for.

The second study's task more truly reflected open-ended creative work. Subjects were asked to develop color schemes for a wristwatch to make it depict the seasons of the year (winter, spring, summer, or fall). This more real-world task afforded a view of how the tools influence more creative tasks, but at the cost of being unable to perfectly assess how well goals were met (that is, there was no single "right" answer by which one could measure solution quality).

The first two studies were identical in design. Both were controlled laboratory studies employing a within-subjects design that varied experimental tool availability. All significant actions within the interface were logged and time-stamped allowing reconstruction of any state visited by a subject.

Subjects completed NASA TLX workload assessment forms after each task to help determine any potential impact the tools may have on perceived levels of cognitive load, and an exit questionnaire assessed user preferences for the tools. These data yielded a significant quantity of empirical data describing what individuals did, but not necessarily why. The third study was designed to get at this latter question.

The third study paired individuals to work collaboratively on the same wristwatch color scheme task as the second study. This design, inspired by the constructive interaction technique by Miyake (1986) has the advantage of externalizing thought processes as individuals work together on the problem. After all tasks were completed, an interview with the subjects enabled the researchers to probe specific questions that arose from analyzing the data from the first two studies.

Instruments such as the NASA TLX or the exit questionnaires are designed to collect data to answer very specific questions. However, user interface logs are raw data and require analysis. Returning to the earlier observation that exploration is highly prized in this community, the researchers developed a set of formal definitions for breadth and depth of exploration, backtracking, and "dead-ends." These could then be applied to the log data to yield measures of how much each activity occurred throughout the studies. Custom visualizations were developed to help convey these concepts.

Several aspects of this evaluation plan are noteworthy:

- Task type was varied to understand how the tools operate under different conditions (tightly constrained tasks with well-defined solutions vs. ill-defined problems with no single, correct answer)
- Multiple types of data were collected, from quantitative to qualitative (user interface usage, workload self-assessment, tool preference, interview data). These data often complement one another, with one data set increasing the value of the other data set
- New metrics were defined to describe aspects of the problem solving process (well-defined measures for breadth and depth of exploration, backtracking, dead-ends)
- Visualizations were created to convey research results

From their studies, they confirmed that current interfaces lead to highly linear problem solving practices and that users more broadly explore when tools are available to facilitate this process. However, they also found a tendency to initially *overuse* these capabilities: Subjects sometimes spent *too much* time exploring and not enough time maturing a single solution. This finding provides a lesson that there can be cases where computational support can detrimentally affect creative processes, even though their design is well-motivated.

More importantly, this research yielded a new set of "yardsticks" for other researchers to employ when evaluating their own tools, specifically how to define breadth and depth of exploration, backtracking, and dead-ends. One of the routes to maturing research in creativity support tools is to promote more evaluations, especially those that afford comparisons between independent research results. Standardized instruments are one method of achieving this end.

The research of Terry and Mynatt is not unique, and makes use of strategies commonplace within the research community. However, with regards to evaluating creativity support tools, the following points are important to keep in mind:

- Creativity happens within a social context, and tools will partially need to be evaluated within this context

- Qualitative methods help reveal user needs, not merely practices (*why* they do what they do, not just *what* they do)
- Traditional metrics such as performance and efficiency are important to evaluating creativity support tools. However, there is a need for richer set of metrics for describing *how* tools influence the problem solving process, and whether these effects are desirable
- The creative process is composed of many smaller sub-tasks, some of which resemble less creative tasks such as optimization. It is important to analyze tools under these various environments to gain a holistic understanding of the tool's strengths and weaknesses in different milieus
- Both quantitative and qualitative data are necessary for evaluation. Empirical studies indicate significant effects, and qualitative studies aid in interpreting *why* these effects arise
- One should seek to learn the "boundaries" of the tool – what its strengths and weaknesses are, and report *both*. Successes are important, but the failures are just as important so others don't make the same mistakes

An example of multiple methods and metrics in a research program.

Research in Creativity Support Tools (CST) (George, Nunamaker, and Valacich, 1992) has involved use of multiple research methodologies. Multiple methodologies including mathematical simulation, software engineering, case study, survey, field study, lab experiment, and conceptual (subjective/argumentative) are illustrated based on an established taxonomy of MIS research methods (Vogel and Nunamaker, 1990). These variety of methodologies need to be called upon to address the multitude and multifaceted research questions that exist pertaining to creativity support tools.

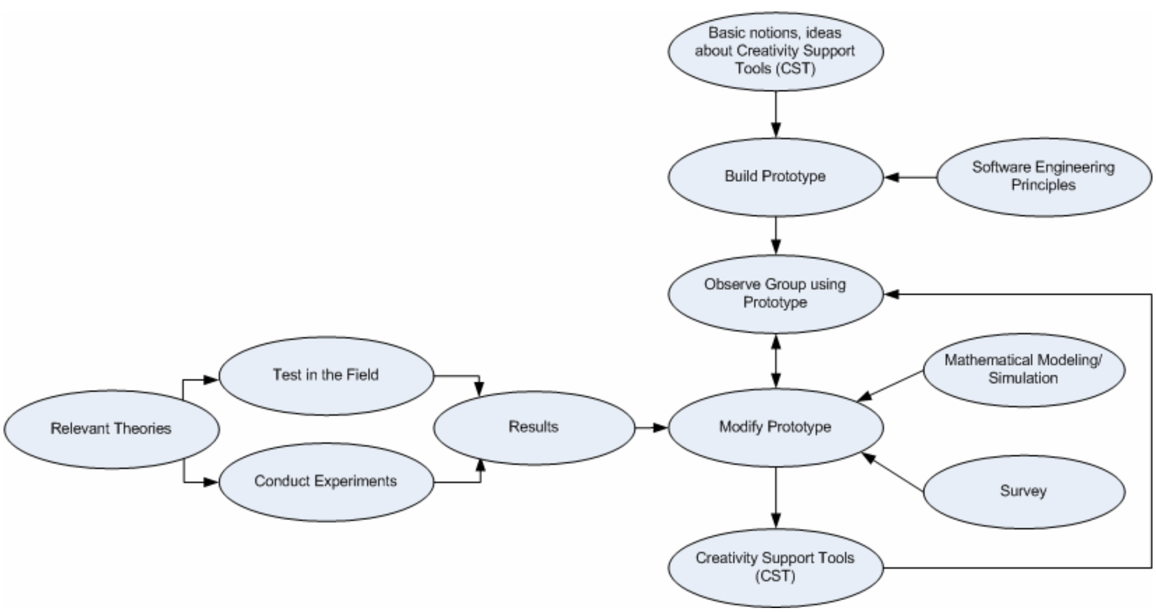

Figure 1: Creativity Support Tools (CST) Development Framework

As the Figure 1 above shows, studying the creativity process with the aid of CST involves crystallizing the few important research notions and ideas about the computer-aided creativity process by building a prototype and enhancing it with the aid of results derived from deployment of multiple methodologies. Software engineering principles are important in building the prototype. Also, early on, it is important to do preliminary testing by observing the groups using the prototype and taking the observations to improve the prototype. Mathematical modeling and simulation play a role in formalizing the process.

Methodologies such as planned experiments, case studies, and field studies are tools for empirical validation and testing that can help in improving the prototype as well as developing a theory for understanding the creativity process in the light of CST.

Creative ideas emerge from novel juxtaposition of concepts in working memory in the context of a creative task. Therefore, within the limits of human working memory, the greater the variety of concepts one considers, the greater is the probability that creative ideas will occur. Group Support Systems (GSS) helps create variety of stimuli which can be far more than those using nominal group techniques (NGT).

Many of the initial research findings related to CST came from the field settings when the initial prototypes were tested in organizational settings. Support for increasing creativity was observed in the field settings. To investigate the process from a theoretical standpoint, similar studies were conducted in the laboratory settings. Similar support was observed in the laboratory settings also. However, researchers noted certain differences between lab and field findings, many of them which can be attributed to differences in the two settings (Dennis, Nunamaker, and Vogel, 1990). Many iterations between field and laboratory experiments resulted in strong empirical validation of GSS as useful CST. Actual field use of these support tools produced effects that were not modeled or measured in the early lab experiments, often because real groups do not perform in a void, but within an organizational context that drives objectives, attitudes, and behaviors in group meetings. Our direct experience is based upon having worked with more than 200 public and private organizations in our own four meeting laboratories, as well as at over 1,500 sites around the world that have been built upon the meeting laboratory model established at Arizona. We have facilitated over 4,000 working sessions for teams and have produced more than 150 research studies in the domain of collaborative technology. An extensive review of case and field studies for CST can be found in (Fjermestad and Hiltz, 2000), while a similar review of experimental studies for CST can be found in (Fjermestad and Hiltz, 1998).

The processes and outcomes of group work in the form of creativity depend upon the interactions among four groups of variables: organizational context, group characteristics, task, and technology. What variables within these four groups have significant effects remains an open question. We have selected 24 variables; clearly there are many others that could be considered (Dennis, Nunamaker, and Vogel, 1990). However, the number of variables also precludes meta-analysis as there are too many variables for the number of studies. Our selection was motivated both by theoretical arguments (i.e. there is some a priori reason to suspect that the variable might affect processes and outcomes) and empirical findings (i.e. there have been differences among studies that have differed in these characteristics).

We discuss below two major variable groupings as related to creativity: organizational context and group characteristics. The discussion is focused around explaining the differences observed in the results from experimental and field studies of creativity tasks. In a nutshell, the results have shown that organizational groups (real groups) outperform experimental groups (nominal groups), when using creativity support tools (CST) (Valacich, Dennis, and Connolly, 1994). Only in the case of manual settings, i.e. in the case of non-CST support settings, nominal groups have been shown to outperform real groups. An extensive literature on studies with brainstorming with nominal groups can be found in (Diehl and Stroebe, 1987).

Organizational Context

We note four organizational contextual factors may be important for productivity of creative ideas. First, organizational culture and behavior norms serve as a guide to the meeting process for organizational groups in field studies. Norms may be lacking in laboratory groups formed for the purpose of an experiment; an assembled group of individuals may be a group in body, but not in spirit. In pre-existing experimental groups, contextual norms may simply be different from the norms of organizational groups.

Second, in organizational groups, group members have incentives to perform. Accomplishing the task successfully means recognition and reward for the group. In some experiments, where the tasks are such that performance can be measured objectively, this has been provided by pay and incentives based on experimental performance.

Third, members of organizational groups may not always have consistent goals and objectives; there may be political elements such that the "best" outcome for some group member(s) is different from that for other group member(s). Tasks in experiments have traditionally presumed the rational model, where organizational decisions are consequences of organizational units using information in an intended rational manner to make choices on behalf of the organization (Huber, 1981), although some (Watson, DeSanctis, and Poole, 1988) have involved what are essentially bargaining tasks which have no right answers. In field studies, objectives have not always followed the rational model. They often have a political component, where organizational decisions are consequences of the application of strategies and tactics by units seeking to influence decision processes in directions that will result in choices favorable to them (Huber, 1981).

Finally, for organizational groups, issues and problems are interrelated. Thus every time an organizational group attempts to resolve a particular problem it needs to consider the problem's potential relationship with all other problems. This generally has not been a concern for groups in laboratory experiments.

In summary, most laboratory experiments have examined student-related organizational cultures without performance incentives but with common objectives without interrelated problems. Most field studies have examined public and/or private sectors with incentives and interrelated problems, but with necessarily the same objectives.

<u>Group Characteristics</u>

There have been many differences between the groups in experimental research and those in the field that may account for differences in findings. First, most experimental groups have been composed of students, while organizational groups have been composed of managers and professionals. Individual characteristics of the two populations may be different.

A second potential factor is the familiarity of group members with the task. Members of organizational groups typically have had more experience with the task, as in general, they address the tasks faced in the on-going management of the organization. In contrast, experimental groups have often had less familiarity with the task they have been assigned.

Third, experimental groups have typically been ad hoc, formed for the sole purpose of the experiment, and have no past history or foreseeable future. Field studies have typically used established groups, for whom the meeting under study is just one meeting in a long series of meetings.

Fourth, participants in experimental studies have generally been peers. While some experiments have studied the effects of an emerging leader or have temporarily assigned a leader for the duration of the experimental session (George, Easton, Nunamaker, and Northcraft, 1990), this form of leadership can be difference than that in organizations. Groups in previous field studies have generally had a distinct hierarchy and/or differing social status among members; the leader was the leader before, during, and after the meeting.

Fifth, participants in experiments have often been first time users of the CST technology. Participants in field studies have also often been first time users, but by the end of the study they have often logged many

hours of use; they are moderately experienced CST users. Observations drawn from a study of inexperienced users of CST may be useful, but may apply on to inexperienced users.

Sixth, researchers have speculated that CST may prove effective for larger groups than smaller groups (Dennis, George, Jessup, Nunamaker, and Vogel, 1988; DeSanctis and Gallupe, 1987). Most experimental research has been focused on small groups (often 3-6 members). In contrast, most field study groups have been larger (typically 10 or more members). Group size, of course, has been shown to have significant impacts on non-CST supported creativity group work.

Finally, the logical size of the group in addition to the physical size of the group is also important. Groups can be considered logically small if there is high overlap in the participants' domain knowledge and skill. The overlap or lack of overlap of skills, traits and abilities has been shown to have different effects in studies of non-CST supported creativity group work.

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Design Principles for Tools to Support Creative Thinking

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Introduction

We have developed a set of "design principles" to guide the development of new creativity support tools – that is, tools that enable people to express themselves creatively and to develop as creative thinkers. Our goal is to develop improved software and user interfaces that empower users to be not only more productive, but more innovative. Potential users of these interfaces 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.

Some of these design principles have appeared previously [Myers 2000][Shneiderman 2000][Resnick 2005][Yamamoto 2005][Hewett 2005][Selker 2005]. 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. 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.

In our analysis, 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 both logical and/or physical representations. A creative composition process is not a routine production process that can be prescribed, and what tools and representations people use strongly affect their courses of actions and thought processes [de la Rocha, 1985][Zhang, 1997][Shirouzu et al. 2002].

While it is difficult to study "creativity" itself, we can study the process by which creative people and teams work, and embody their best practices in tools that can aid others in emulating those processes. Examples include the IDEO design team "brainstormer" process has been nicely documented and used by many other organizations [Kelly 2001] and the widely-used TRIZ method for systematic innovation [Mann 2002]. Strategies for studying creativity support tools are discussed in this report's section titled "Creativity Support Tool Evaluation Methods and Metrics."

1. Support Exploration

An important requirement for creativity is to be able to try out many different alternatives. Almost by definition, creative work means that the final design is not necessarily known at the outset, so users must be encouraged to explore the space [Fischer 1994]. This has a number of implications on the tools. Exploratory programming has been promoted for a long time [Sheil 1983], but most tools still focus on projects where the outcome is well-known in advance. In the terms of Green and Petre [Green 1996], we want systems with "low viscosity" – that make it easy to change all aspects of the design.

First, it must be very easy to try things out, and then backtrack when unsuccessful. This means that the tools must be trustworthy so that users are comfortable trying things. For example, a very good Undo capability is required in the tools. Implementing Undo can be quite difficult however [Myers 1996], so many research systems leave it off. The rich histories that are required to support undo can also be useful for creating programming-by-demonstration interfaces [Myers 1992], where users teach the system how to automate repetitive tasks by giving examples. Previewing mechanisms [Terry 2002] and set-based operations [Terry 2004] have also been proposed and tested to support such processes.

A second requirement is that the tools be "self-revealing" so that it is clear to users what can be done. If the flexibility is not apparent, it will not be used. This is especially important as users are learning the tools. The tools must also be facile and unencumbering, so that expert users can try out the different alternatives very quickly. Finally, tools must be pleasurable and fun to use. When people are stressed or concentrating too much effort on how to use the tools themselves, then they will have less cognitive resources left over for use on finding creative solutions to their tasks.

Spreadsheets are famous for giving people an ability to compare results in what-if scenarios [Brown 1987], by enabling the user to easily separate what will stay fixed (the formulas) from what should vary (the values to be explored). In the user interface realm, tools such as Flash and Visual Basic are popular because they allow prototypes to be created, evaluated and modified quickly.

Another way to support exploration is to make it very fast to "sketch" out different alternatives at the early stages of design. Professional user interface designers will often try out dozens of ideas by drawing on paper or a whiteboard, before starting to write code

for a real implementation. The goal is to allow a partial effort to get a partial result quickly. Tools to facilitate this kind of sketchy exploration include Silk [Landay 1995] and Denim [Lin 2002], which specifically focus on sketching screens and storyboards of interactive behaviors.

Supporting exploration requires functionality made available through careful interaction design. We view a computational tool as something that provides materials with which users interact to create a situation that "talks back to the users" [Schoen 1983][Nakakoji 2000a]. Tools for fostering, not obstructing, creativity need to be designed around the understanding of what representations users need to interact with [Yamamoto 2005].

The interaction design of a tool influences a user's cognitive process. By interaction design, we mean to determine the representations and operations of an application system [Yamamoto 2005]. Systems for supporting creative processes need to enable users not only to compose artifacts, but also to think of what to compose as artifacts [Nakakoji 2005]. Historically, existing tools and application systems have been mostly used to digitally compose artifacts. Examples are word-processing software, image-processing software, or spreadsheet applications. Elaborated 3D CAD systems are found effective in helping architects to compose solutions but obstructive to their creative exploration [Lawson 1994].

2. Low Threshold, High Ceiling, and Wide Walls

Effective tool designs should make it easy for novices to get started (low threshold) but also possible for experts to work on increasingly sophisticated projects (high ceiling) [Myers 2000]. The low threshold means that the interface should not be intimidating, and should give users immediate confidence that they can succeed. The high ceiling means that the tools are powerful and can create sophisticated, complete solutions. Too often tools that enable creative thinking may be quite hard to learn (they don't have a low threshold). Instead, they focus on providing numerous powerful features so that experts can assemble results quickly.

Now, we add a third goal: *wide walls*. That is, creativity support tools should support and suggest a wide range of explorations. By not including predefined widgets, the Flash tool encourages designers to explore many different ways to control the interaction, instead of just using buttons and scroll bars. Carnegie Mellon's Alice tool has enabled the creation of a wide variety of three-dimensional stories, games, and interactive Virtual Reality experiences [Conway 2000], and the Disney/Carnegie Mellon Panda3d System (panda3d.org) has allowed theme park, online, and classroom content creation. When kids use MIT's Programmable LEGO Bricks, for instance, they can create anything from a robotic creature to a "smart" house to an interactive sculpture to a musical instrument [Resnick 1993][Resnick 1996]. We want users to work on projects that grow out of their own interests and passions – which means that the creativity support tools need to support a wide range of different types of projects.

When evaluating the use of creativity support tools, we consider diversity of outcomes as an indicator of success. If the creations are all similar to one another, we feel that something has gone wrong. And if, after finishing one project, users feel that they are "done" with the tool, again we feel as if we have failed. Creativity support tools should define a space to explore, not a collection of specific activities. And our hope is that users will continually surprise themselves (and surprise us too) as they explore the space of possibilities. As an example, it was a surprise that kids would use MIT's Programmable LEGO Bricks to measure their speed on rollerblades, or to create a machine for polishing and buffing their fingernails [Resnick 2000].

The problem with systems that aim for a low threshold is that they usually are quite limited in what they can do, so users are either constrained, or else need to find "work-arounds" to achieve what they want. Tools with high ceilings tend to require significant training and effort to learn how to use. And wide walls means that there are very general primitives that users must learn how to combine.

One strategy to try to achieve all three is to explicitly include elements and features that can be used in many different ways. The design challenge is to be specific enough so that users can quickly understand how to use the features (low threshold), but general enough so that users can continue to find new ways to use them (wide walls). The tool should help users learn how to use the features, for example with mouse-overs, tool-tips, and a variety of examples, so users can make the transition necessary to understand the variety of possible uses.

3. Support Many Paths and Many Styles

When MIT researchers were testing an early version of the computer-controlled LEGO technology, they tested prototypes in a fourth-grade classroom where students wanted to build an amusement park. One group of students decided to create a merry-go-round. They carefully drew up plans, built the mechanisms, and then wrote a program to make the ride spin round-and-round whenever someone pressed a touch sensor. Within a couple hours, their merry-go-round was working. Another group of students decided to build a Ferris wheel. But before the ride was working, they put it aside and started building a refreshment stand next to the Ferris wheel. The developers were concerned: the refreshment stand did not have any motor or sensors or programming. They worried that the students would miss out on some of the powerful ideas underlying the LEGO/Logo activity. But they didn't interfere. After finishing the refreshment stand, the group built a wall around the amusement park, created a parking lot, and added lots of little LEGO people walking into the park. Then, finally, they went back and finished their Ferris wheel.

These two groups represent two very different styles of playing, designing, and thinking. Turkle and Papert [Turkle 1990] have described these styles as "hard" (the first group) and "soft" (the second). The hard and soft approaches, they explain, "are each characterized by a cluster of attributes. Some involve organization of work (the hards

prefer abstract thinking and systematic planning; the softs prefer a negotiational approach and concrete forms of reasoning); other attributes concern the kind of relationship that the subject forms with computational objects. Hard mastery is characterized by a distanced stance, soft mastery by a closeness to objects."

Similarly, faculty at CMU through a decade of working with creative people at Walt Disney Imagineering, Electronic Arts, and in CMU's Entertainment Technology Center (ETC) (see www.etc.cmu.edu) have identified similarities and differences between "left brain" (logical, analytical) and "right brain" (holistic, intuitive) thinkers. You might think that people who do Art and Graphic Design would be the "soft" or "right brain" group (as people who can draw), versus people who do Science and Engineering (as people who can do math). But in fact, people who focus on art and science often have more in common with each other, as people who focus on finding the "truth", compared to Graphic Design and Engineering, who are people who try to solve problems, often within constraints such as budget, time, and client demands.

In many math and science classrooms, the hard approach is privileged, viewed as superior to the soft approach. Turkle and Papert argue for an "epistemological pluralism" that recognizes the soft approach as different, not inferior. We should take a similar stance in the design of new creativity support tools, putting a high priority on supporting learners of all different styles and approaches. We should pay special attention to make sure that technologies and activities are accessible and appealing to the softs; since math and science activities have traditionally been biased in favor of the hards, we want to work affirmatively to close the gap.

4. Support Collaboration

An important implication of this diversity is the need to provide support for *collaboration* in the tools. In all of our projects, in schools, and in the "real world," most creative work is done in teams. At CMU, the ETC specifically focuses on creating teams that include people with various strengths. But diversity of talent will appear in all teams. It is important that the creativity support tools allow each person to contribute using their own talent. For example, the Building Virtual Worlds course at Carnegie Mellon (etc.cmu.edu/curriculum/bvw.html) requires creating 3D interactive virtual worlds, which combine art work, sound design, script writing, and programming. The tools allow team members to work on their own parts in parallel, but more work is needed on supporting the integration and iteration which results from these kinds of activities.

With the advent of the Internet, another form of "collaboration" has become prevalent: finding good material from others by using search tools like Google. Creativity support tools should foster a community of users to share their creations, and the tricks and techniques they have discovered for using the tools. Research shows that when confronted by a challenge, experienced and novice creators alike will go to Google to see if they can find the answer. And with professional tools, often they will find a host of examples, discussion and documentation posted by other users. Some research tools have

built-in techniques to help with posting creations (e.g., Agentsheets.com [Repenning 2004], Alice.org [Conway 2000]), and current research is looking at how other people's examples can help people learn new systems [Stylos 2005]. Commercial tools such as Spotfire (http://www.spotfire.com) provide numerous strategies for sending results by email and posting results to a website with an automatically generated chat window to promote discussion. Social and psychological factors such as trust and appropriation play an important role in support of collaborative creativity [Nakakoji 2000b][Shneiderman 2000].

The NSF is already funding a number of "collaboratories" to help bring scientists working in the same field or on related problems together. Examples include The Gene Ontology project (http://www.geneontology.org/), the Protein Data Bank (http://www.rcsb.org/pdb/), the Collaboratory for Research on Electronic Work (http://www.crew.umich.edu/), etc.

5. Support Open Interchange

The creative process will not usually be supported by a *single* tool, but rather will require that the user orchestrate a variety of tools each of which supports part of the task. Creativity support tools should seamlessly interoperate with other tools. This includes the ability to easily import and export data from conventional tools such as spreadsheets, word processors and data analysis tools, and also with other creativity support tools. This requires that the data formats in the files be open and well-defined. Fortunately, the increasing pervasiveness of XML and projects such as the Gene Ontology (http://www.geneontology.org/) (which provides a controlled vocabulary to describe gene and gene product attributes in any organism) show promise in this direction.

Another form of openness allows extensibility of the tools themselves. Professional tools increasingly provide a "plug-in" architecture, or an "open data model" [Myers 1998] to support extensibility. This has long been available for artistic tools like PhotoShop to allow capable creative people to define their own operations that work on the shared data types. Another example is the Eclipse tool (www.eclipse.org), which is not just a Java programming environment, but actually is a kernel into which many pieces can be plugged together to create a wide variety of environments to support different activities. The COM interfaces for Microsoft Office tools provide similar extensibility, although these are usually used to make business operations more efficient, rather than more creative. The professional suite of tools from companies such as AutoDesk (http://www.autodesk.com) and Adobe (http://www.adobe.com), are largely designed to facilitate taking the results from one tool into another.

Integration of operations across tools could allow smoother coordination across windows and better integration of tools. We have proposed operations such as getting an English definition, a French translation, or a medical dictionary report just by clicking on a word [Shneiderman 2000], and a "smart" clipboard that allows easy transformation of

structured information among many applications just using the familiar copy-and-paste operation [Stylos 2004].

6. Make It As Simple As Possible - and Maybe Even Simpler

In some ways, this design principle seems obvious. Who wants needless complication? But there is no doubt that technology-based products have become more and more complex. One reason is "creeping featurism": advances in technology make it possible to add new features, so each new generation of products has more and more features. This trend is reinforced by the belief among marketing professionals that it's quite hard to sell a product as "simpler," but much easier to sell it as "containing more features."

A related problem is getting a simpler design/tool past the "gatekeeper experts." Particularly in technical fields like Computer Science, a great deal of the self-image of the practitioners has historically been linked to their ability to master complex tools themselves. Later, simpler (and better designed) tools are often denigrated as "toys" – for example, while many would find this hard to believe, the introduction of the computer mouse was widely derided at the time by "serious" computer scientists.

We yearn for a return to the clean usability of the Macintosh of the 1980s. We see a role for complexity: we make use of ever-more complex technologies, and we want to help users accomplish complex tasks. But we want the user experience to be simple. We try to develop systems that offer the simplest ways to do the most complex things.

We have found that reducing the number of features can actually improve the user experience. What initially seems like a constraint or limitation can, in fact, foster new forms of creativity. In the mid-1990s, for example, MIT researchers had developed a Programmable LEGO Brick that was roughly the size of a child's juice box. It could control four motors and receive inputs from six sensors. For a sponsor event at the Media Lab, some interactive decorations for the tables were needed. All of the capabilities of the Programmable Brick were not necessary, so a smaller, scaled-down version was quickly developed, roughly the size of a matchbox car. It could control only two motors with inputs from only two sensors. This was expected to be a short-lived project, since they "knew" that most users would want more motors and more sensors. But once the scaled-down version (called a Cricket) was available, people kept finding more and more creative applications for it, in spite of (or perhaps because of?) its apparent limitations. Even though the original Programmable Brick was better for certain projects, the simplicity of the Cricket won out.

7. Choose Black Boxes Carefully

In designing creativity support tools, one of the most important decisions is the choice of the "primitive elements" that users will manipulate. This choice determines, to a large

extent, what ideas users can explore with the tool – and what ideas remain hidden from view.

When kids build robots with MIT's Programmable Bricks, for instance, they learn about mechanisms and gearing, and they learn about feedback and control. But they generally don't learn about the inner workings of motors. The motor remains a black box. If you wanted to help kids learn how motors work, you should design a construction kit with lower-level building blocks, so that kids could build their own motors.

Similarly, the choice of the basic "building blocks" in a programming language determines what kids are likely learn as they use the language. When kids put together Logo commands like **forward** and **right** into instructions like **repeat 4 [forward 50 right 90]** (to make a square) or **repeat 360 [forward 1 right 1]** (to make a circle), they gain a better understanding of programming concepts, and it has been argued that they also learn important mathematical and geometric concepts [Papert 1980]. But the primitive command **forward** is still a black box. Each time the turtle moves, the computer must calculate new x and y positions from the original x and y positions using trigonometric calculations. These calculations are hidden from the user. If the goal of the construction kit were to help kids learn these types of trigonometric calculations, then the turtle would be a bad black box. But by hiding these calculations inside a black box, the turtle frees the user to experiment and explore other mathematical and geometric ideas.

All language and toolkit designers face the same challenge. This is closely related to our point above about floor versus ceiling – the higher-level the primitives, the easier they are to use, but the less they can do. But even at the same level of capability, there are easier and more difficult ways to present the same functions. The designers of Alice rejected using conventional matrix representations for graphical transformations because it is not understood by the target audience [Conway 2000]. In the HANDS language, animation is built-in, so characters can be made to move simply by setting a speed and direction, rather requiring calculations of how far to move with each elapsed time interval [Pane 2002]. Similarly, for the language for programming the Cricket, the original design used the conventional Red, Green, Blue parameters to **setcolor.** This representation provides great power and flexibility, but kids found it difficult to map inputs from a single sensor into meaningful color values (for example, red for low values, blue/purple for high values). So a simpler **setcolor** command was added with just a single input that ranges from 0 to 100 (with 0 at the red end of the spectrum, 100 at the blue end), making it easy for kids to map sensor inputs to colors along the spectrum.. In these three examples, the goal was to enable the users to achieve a certain effect, not to teach the underlying principles (linear algebra, physics of motion, or the red-green-blue composition of light), so the simplifications were appropriate.

8. Invent Things That You Would Want To Use Yourself

At first blush, this design principle might seem incredibly egocentric. And, indeed, there is a danger of over-generalizing from your own personal tastes and interests. But we have

found that we do a much better job as designers of creativity support tools when we ourselves really enjoy using the tools that we are building.

We feel that this approach is, ultimately, more respectful to users of the technology. Why should we impose on users systems that we don't enjoy using ourselves? For example, we are generally skeptical of educational software that, in an effort to encourage students to reflect on their actions, requires that they annotate each action. We wouldn't want to do that with the software that we use, so why should we require it of students? Software engineering tools that require commenting, rather than encourage it, are similarly disliked by users.

There is an additional, perhaps less obvious, reason why we try to invent creativity support tools that we enjoy using ourselves. Creativity support tools can not succeed in a vacuum: they work best within communities where people share their expertise and experiences with one another (see this report section titled "Creativity and Distributed Intelligence" for further discussions of social creativity). When students use creativity support tools, for example, they require support from teachers, parents, and mentors. In developing creativity support tools for students, we need to build not only new technologies, but also communities of people who can help students learn with those new technologies. And we have found that it is easiest to build those communities if everyone involved (adults as well as students) enjoy using the technologies. In New York, for example, groups of MIT alumni have been volunteering their time to help kids at Computer Clubhouses (after-school centers for youth from low-income communities) learn to use the Programmable Bricks. The MIT alumni are motivated, in part, by a desire to help youth in low-income communities. But there is no doubt that they are also motivated by their own desire to build robots.

9. Balance user suggestions, with observation and participatory processes

Most successful designers seek to understand their users, in order to design products well-matched to the needs of their users. They invest considerable time observing and interviewing users, talking with focus groups, asking users for suggestions and feedback on features, and inviting users to participate in design processes. There are dangers to too little or too much involvement of the users, so thoughtful and balanced approaches are needed ([Druin, 2002] [Nielsen 1993] [Shneiderman 2004]).

Some researchers worry that users may ask for impractical or infeasible features. In other cases, users ask for only incremental changes, not aware of the possibilities of radical change. With early versions of Logo software in the 1980s, users often suggested new ways for the turtle to draw – but they never suggested the addition of paint tools.

Another concern is that users may ask for more flexibility than is needed or desirable. Often, designs with well-chosen parameters are more successful than designs with fully-adjustable parameters. We are all in favor of giving control to users – but only where control will really make a difference in their experiences. Sometimes users may request

numerous “local” or specific features without sufficiently recognizing “global” design imperatives, resulting in a “kitchen sink” otucome (as in “throw in everything but the kitchen sink”).

One alternative to asking users to suggest features is to observe users interacting with prototypes, and infer what they want (and don’t want) from their actions. Often, their actions speak louder than their words. It is usually apparent when users get frustrated, even if they don’t articulate their frustration. When we observe users repeatedly making the same “mistake” with a prototype, we sometimes are able to revise the software so that it behaves in the way that users had expected. In early versions of the Alice system, for example, users repeatedly made syntax errors and repeatedly asked for the system to “be smarter” at understanding their typing errors; instead, the system’s designers realized that having to deal with syntax at all was problematic, and built a completely drag-and-drop user interface where it was no longer possible to form a syntactically invalid program.

Other design teams have emphasized participatory methods that engage representative users actively over long periods of time as members of the team [Muller 2002]. These user representatives may have to invest substantial effort to learn more about design constraints and possibilities. Evidence is strong that projects that include users in the design process result in greater acceptance by the broader user community. The greater acceptance may be due to the insights and more accurate data from users, as well as the ego investment and sympathy generated by having user representatives as part of the design team.

10. Iterate, Iterate - Then Iterate Again

Another standard principle of user interface design that we would like to re-emphasize for creativity support tools is the importance of iterative design using prototypes. In designing creativity support tools, we put a high priority on “tinkerability” – we want to encourage users to mess with the materials, to try out multiple alternatives, to shift directions in the middle of the process, to take things apart and create new versions.

Just as we want users to iterate their designs, we apply the same principle to ourselves. In developing new technologies, we have found that we never get things quite right on the first try. We are constantly critiquing, adjusting, modifying, and revising. The ability to develop rapid prototypes is critically important in this process. We find that storyboards are not enough; we want functioning prototypes. Initial prototypes don’t need to work perfectly, just well enough for us (and our users) to play with, to experiment with, to talk about.

One thing most system buildings and designers do not have a strong enough appreciation of is the concept of “iterate just enough to do the next test.” It is crucial to be able to quickly

- observe users with a given iteration of a system
- synthesize design changes as a result of that feedback

- implement (and functionally test) those changes to the tool

and then repeat that process. In a perfect world, one could go around this loop once every day or week.

In his book *Serious Play*, Michael Schrage argues that prototypes are especially helpful as conversation starters, to catalyze discussions among designers and potential users [Schrage 1999]. We agree. We find that our best conversations (and our best ideas) happen when we start to play with new prototypes – and observe users playing with the prototypes. Almost as soon as we start to play with (and talk about) one prototype, we start to think about building the next. This process requires both the right tools (to support rapid development of new prototypes) and the right mindset (to be willing to throw out a prototype soon after creating it).

11. Design for Designers

By creating you become creative.

In designing new creativity support tools, it is important to design for designers – that is, design tools that enable others to design, create, and invent things [Papert 1980][Resnick 2002] (see also this report's section titled "Creativity Support Tools for *and* by the New Media Arts Community" for a further discussion).

The traditional LEGO construction kit is a model for what we are trying to achieve with new creativity support tools. With traditional LEGO kits, users are provided with a simple set of parts with which they can design and create a diverse collection of constructions. LEGO kits certainly enable users to express themselves creatively, but new computationally-based creativity support tools go further, enabling users to create not only static, structural artifacts but also dynamic, interactive artifacts: music, video, animations, interfaces. Software-based creativity support tools have an added advantage in that they (and their resulting products) can be distributed widely at low cost.

The analogy with LEGO kits also suggests an important counter-example. In recent years, a growing number of LEGO kits highlight a specific construction (such as a Star Wars spaceship or a Harry Potter castle), with many specialized pieces. Although it is possible to use these kits to create a variety of constructions, many kids build the model suggested on the package, or perhaps slight variants, and nothing more. This is analogous to using a paint-by-numbers kit. These kits clearly encourage "hands-on activity," but they are less effective (compared with traditional LEGO kits) at fostering creative thinking. Our goal is to develop technologies that not only engage users in composing artifacts, but also encourage (and support) them to explore the ideas underlying their constructions.

Another example as a model for what our research tries to achieve is paper and pencil as a tool used by creative practitioners, such as architectural designers. Hand-drawn

sketches and diagrams have been found essential for architects' creative reflection [Arnheim 1969][Lawson 1994]. Not only the drawn diagrams, but the process of drawing helps designers engaging in reflection-in-action [Schoen 1983]. Tools have been designed, developed and tested to support such sketching processes in several domains, including architectural design [Gross 1996], software interface and Web page design [Landay 2001], and industrial design [Hoeben 2005]. Fundamental aspects of sketching for creative thinking have been identified and applied in non-diagramic domains, such as writing and movie-compositions, by using two-dimensional spatial positioning as a representation [Yamamoto 2005]

Writing software is a creative activity, and the authors of this report are programmers who try to be creative, so we would like tools that help us creatively write software. This is somewhat recursive; since we want creativity support software-writing tools that help us create creativity support tools for other tasks as well. The tools we create for ourselves should therefore support all of the guidelines discussed above. Therefore, we should follow good software engineering practices so that the tools themselves are easily modified. This has been the focus of much of the research work in creating flexible user interface software tools [Ousterhout 1994][Myers 1997][Bederson 2004].

12. Evaluation of Tools

One important issue with the design of creativity support tools is how they can be evaluated (see this report's section titled "Creativity Support Tool Evaluation Methods and Metrics"). How do you know if a tool is being helpful? Human-computer interaction professionals are used to measuring the effectiveness and efficiency of tools, but how do you measure if it supports creativity? As discussed above, tools that are *not* effective and efficient will probably hinder creativity, but it isn't clear that the reverse will hold. To try to measure creativity, the Silk system designers evaluated many different properties, including the number of different designs produced, the variability of the components used, the variety of questions about the designs from collaborators, etc. [Landay 1996], but these still do not really get at the *quality* of the solution. It is still an open question how to measure the extent to which a tool fosters creative thinking. While the rigor of controlled studies makes them the traditional method of scientific research, longitudinal studies with active users for weeks or months seem a valid method to gain deep insights about what is helpful (and why) to creative individuals [Seo 2005].

We have no delusions that evaluating tools is an easy task, but we also believe that the potential impact of improved tools would be enormous in amplifying and inspiring creativity.

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Creativity Support Tools for *and* by the New Media Arts Community

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INTRODUCTION

The new media arts are a particularly fertile domain for the development of creativity support tools that both supplement creative practices and contribute valuable research methodologies for other disciplines. Many parallel research concerns of new media art practitioners and researchers are found in the Human Computer Interaction and software engineering communities, including: education technology, computer supported collaborative work, data visualization, database architecture, and tools development research in pervasive computing, tangible interfaces, emotion and context aware interaction, and so on. New media arts practitioners and researchers should be regarded as valuable contributors *not only as users needing better creativity support tools (CST) to enhance their own creative process, but also as the designers of experimental and innovative creativity support tools capable of providing insights and indications* for:

1. Categorizing what features of the *interface* and what *system components* engender and satisfy the requirements of these multiple forms of creativity. Section 1, *Creativity Support Tools development for New Media Arts Curriculum* presents examples of tools that have been designed for new media art production, and potential tool features, that could empower the creative potentials of practitioners across all fields of creative production.
2. Defining the range of potential "creativities" (Sternberg, 2005) for which new technologies and tools may be developed. Section 2, *Research-In- Practice,* introduces works by new media artists that have developed creativity support tools that are used by a large user-base of artists and other professionals as a result of their own creative practices. Sometimes this is a primary outcome, often a residual effect from developing robust tools for one's own art practice that can withstand a variety of user interaction and manipulation. This section also presents cases of new media arts research-in-practice that hold the similar broad reaching potentials.
3. Developing more comprehensive and appropriate *evaluation methodologies* grounded in the "research-in-practice" approach. Section 3, *Policy Making and New Media Arts*, is a brief overview of international policies for new media arts practices. Many of these policies recognize the innovative potentials for effecting research in science and technology including and beyond the arts.

This document, generated from presentations and conversations at the NSF Creativity Support Tools Workshop held in Washington D.C. in June, 2005, presents example cases of the contributions that new media art pedagogy, practice and research can provide in the development of support tools that promote the situated, affective and social aspects of creativity.

1. CST DEVELOPMENT FOR NEW MEDIA ARTS CURRICULUM

Education technology research by information technology, education, and public policy researchers has grown tremendously as the Internet has become the de facto platform for the dissemination of information, and platform for community-based collaborations. From component based authoring environments to cognitive tutors, much of the research in this area has been funded by the National Science Foundation to support STEM (Science, Technology, Engineering, and Mathematics) disciplines. Our tendency to separate the STEM disciplines from creativity, culture and humanities sets forth a pattern of missed opportunities to develop new technologies that could help to solve research problems for disciplines that present alternative perspectives on data acquisition, analysis, and manipulation. In recent years new media arts practices have entered the mainstream. Many international universities are actively creating new media arts programs geared towards artists that both use and create technologies (Jaimes & Jennings, 2004). NSF has recently funded a few research initiatives to develop curriculum modules that integrate computer science and new media arts (Integration Digital Media Curriculum Development (NSF DUE- 0340969) and the Digital Media Curriculum Development Project (NSF DUE-0127280). Pedagogical practices in new media arts are based on problem solving through open exploration of conceptual ideas that sometimes conform to, but mostly challenge, the intended functionalities of technology-based tools. This pedagogical practice of open tools usage sits in contrast to the typical computer science curriculum that is based on learning through

constrained problem solving. In the later case, students are typically given assignments that have a limited number of acceptable solution variations. The open and indeterminate nature of new media arts practice presents unique opportunities for developers of creativity support tools to incorporate complex programming abstractions, relational databases, integrated search functionalities, and scaffolded interfaces as a means to create more flexible creativity support tools for new media arts students and practitioners. (Bransford & Brown, 1999)

1.1 NEW MEDIA ARTS CURRICULUM CASE #1:
Design of Appropriate Tools Features for Open Ended Creative Production

Fig. 1 – 3. Human Computer Interaction and Interaction Design students working with electronics in the Physical Computing: Wearables offered by the School of Art at CMU.

Students in the Introduction to New Media Arts class at Carnegie Mellon University were given an assignment to create a sound self-portrait five minutes in length. The main rule was a restriction on the length of a sound bite to ten seconds. This rule was given to encourage the exploration of composition by editing multiple sound layers. PEAK, a sound editing application, was selected because of its relative easy to use and happens to be the introductory application installed on all of our computers. An advanced sound editing application, though more flexible, was not introduced at this stage to give students, of all levels, a sense of efficacy that would be difficult with a more advanced application. PEAK is also an application that replaces Sound Edit Pro, a Macintosh application from the early 1990's. Both applications are simple to use but have a couple of profound differences. Sound Edit Pro enabled artists to approach sound editing in a much more fluid and conceptual manner with an interface that did not assume that the end product was to be a perfectly balanced stereo recording. Thus it did not put constraints on how the user could combine multiple layers of sound across multiple sound channels. PEAK, on the other hand comes with more sound synthesis filters and plug-ins than any practitioner may ever want to use. It has savvy widgets for editing within a sound channel, but has very limited flexibility for mixing more than two mono tracks at a time, making the combination of multiple sound layers an unnecessarily arduous task. The students persevered through the assignment and produced wonderfully complex sound compositions, because of their deep interest in contemporary sound culture. Benefits they gained from working with this inflexible interface included the realization that working with computer-based tools requires, focus, patience, and the willingness to fail often before producing a satisfactory product. However, they could have learned these lessons with an application better attuned to alternative interpretations of assumed use by its developers. This would be an interface with features for the beginning professional that respect her developing aesthetic voice.

1.2 NEW MEDIA ARTS CURRICULUM CASE #2:
Tools to Support Mixed Skills Level Classes

Upon completion of the compulsory introductory classes in new media arts, the Carnegie Mellon University art student can enroll in intermediate and advance elective classes that range from video and sound production and animation, to interactive programming and physical computing. These classes are also very popular for students in the Human Computer Interaction Institute, Electrical and Computing engineering, Entertainment Technology Center, College of Humanities and Social Sciences, and School of Design. This mix of students enables opportunities for cross-disciplinary learning and collaboration. The classes attract a broad range of students for several reasons. Students learn specific technology-based tools for creative arts and interactive design prototypes. Students can explore these techniques in a curriculum that encourages freedom of exploration and expression. Many of our computer science and engineering students enjoy these classes because they can engage in open-ended learning, which is generally a different approach than the typical exercise or lab-based technology-learning pedagogy.

The broad range of students' skills in these classes presents a few creativity support tool development opportunities The first is the design of tools that can accommodate a range of skills– from beginner to advance – with proper

scaffold features and functionalities for each user level. The second is the development of multi-level help modules that can assist students and instructors in facilitating a broad range of questions and possible solutions. For example, it would be wonderful to have a cognitive tutor that notices that a student with beginning skills levels continuously gets a syntax error in her code which she is having difficulty correcting. After analyzing and finding no errors in the code structure, the help module recommends that she check her spelling. Another example if a student wants multiple sprites on the stage to design a Tetris game like interface should he be instructed to create each sprite as a unique entity – a long and tedious process that uses a minimum of code, or should he delve into property lists and object oriented programming – far more efficient but requires a basic knowledge of programming. Or, should he be encouraged to implement sorting and advanced search algorithms that allow him to develop an intelligent self-playing game. These are not hypothetical examples, but the range of students I have seen in new media art classes taught in the School of Art at Carnegie Mellon University and surely a case that is replicated at other universities.

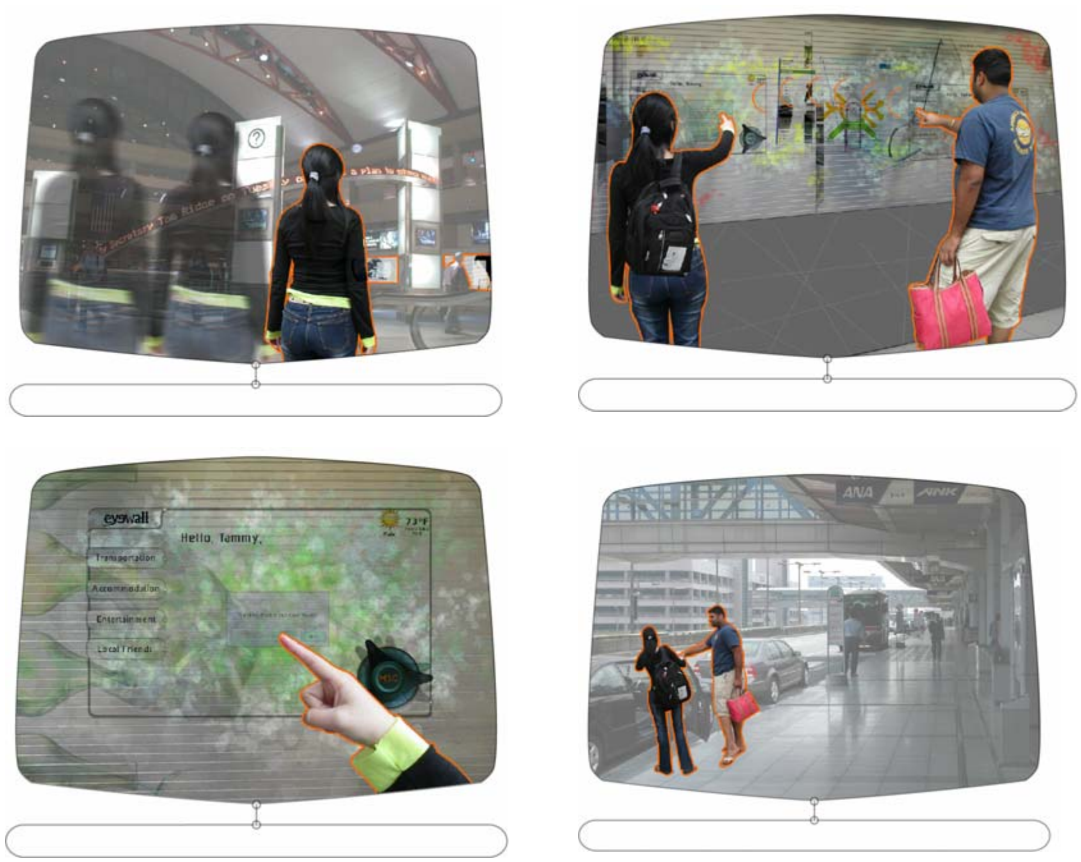


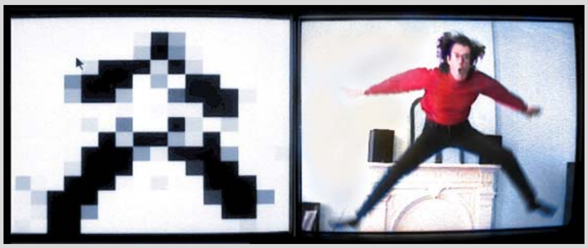
Fig. 4 – 7. Storyboard excerpts from Critical Interaction Design class. Students involved were from Human Computer Interaction, Architecture, Entertainment Technology Center and School of Design at Carnegie Mellon University.

1.3 NEW MEDIA ARTS CURRICULUM CASE #3:
Holistic Presentation Tools

Students taking interaction design classes are often required to work in groups to solve a particular design /human computer interaction interface problem. They are typically given a hypothetical situation to ideate, visualize, and present. Students are encouraged to select very creative means to explore and represent their ideas including text, graphics, photographs, video, theater, 3D animation, sound, programming examples, etc…. It is the student team's task to come up with methods to formalize their needs analysis research, aggregate and negotiate their ideas and produce a visual or functional demo of the interface, application, or gadget. Unfortunately, all of the effort in this work is often reduced to a power point presentation for class-wide discussion and critique. Here is a tremendous opportunity to develop a tool, or set of interoperable tools to support all the requirements as described above without forcing the final presentation to be formatted into bullet point lists.

2. "RESEARCH-IN-PRACTICE"
Creativity Support Tools for *and* by the New Media Arts Community

The new media arts are characterized by what is usually referred to as "research-in-practice": an *experimentalism* and *reflexivity* that bring artists to link creative research and practice in a "highly responsive, iterative process where new insights are fed back quickly into the development process" (Candy & Edmonds, 2005). The new media arts express a *risk-taking* and *subversive* attitude, ultimately seeking *cultural acts* through which to provide society with entry points for change (for example, in the very definition of what is creativity and how it can be supported). Stephen Wilson's "Information Arts: Intersections of Art, Science and Technology" (Wilson, 2002) is an encyclopedic archive of arts, technology and science collaborations exploring new ideas that challenge and contribute alternative perspectives on research practice and tools development across nearly every category of science and technology research from microbiology to nanotechnology to augmented reality.



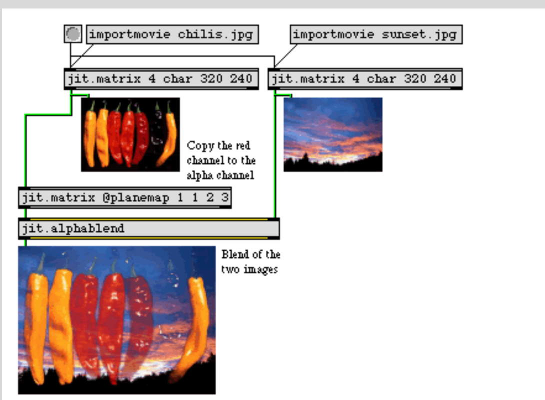


Fig. 8 . David Rokeby, Very Nervous System (1990) ; Fig. 9. Paul Kaiser with Bill T. Jones, Ghost Catching (1999) ; Fig. 10.; Screen shot of Cycling 74 MAX / Jitter interface; Fig. 11. Char Davies, navigation technologies developed for Osmose virtual environment (1995).

Examples of innovative tools created within the new media arts community include, David Rokeby's "Very Nervous System", a computer vision system used by many installation artists and stage performers. Miller Puckett's MAX, distributed by Cycling 74 and his open source version Pure Data (PD) has opened the door to real-time audio and video synthesis and analysis as well as controlling external equipment for theatrical performances for students and professionals working in a variety of media-based fields. Char Davies influence on the graphical user interface and aesthetic filters for SoftImage 3D rendering software represents another interesting case illustrating how novel ideas from the new media arts have influenced the aesthetics of mass media and Hollywood cinema, as well as physical navigation of virtual environments. Paul Kaiser's work with choreographer Bill T. Jones and computer programmer Shelley Eshkar has produced new techniques for real-time motion capture and visual processing. Donna Cox's visualizations of the universe have aided school children and scientist to understand phenomena like the "big bang."

We live in a culture that tends to separate research and acquisition of new knowledge into two general

camps, applied technical research and aesthetic and social research. The HCI community has made great progress in reuniting social and technical inquiry. Inclusion of new media arts practices and research presents the opportunity to not only integrate aesthetic inquiry with the socio-technical platform of HCI, but also deliver an influential impact on domains outside of the arts, for example, investigating the relationships between metadata, multimedia content, and culture; developing novel forms and tools for interaction with data; understanding the influence of different narrative traditions on data collection and presentation and on the design of novel forms of digital representations that extend beyond the pervasive WIMP model (Jaimes & Jennings, 2004).

2.1. CASE STUDIES

This section presents innovative principles and interface features created by new media artists that have impact on the future development of creativity support tools within and outside of the new media arts research and practice aligned with pervasive, tangible and collaborative screen-based development methods. These principles and features support: (a) *temporal, spatial and conceptual distribution across multiple interaction spaces*; (b) *emotion and context aware interaction to nourish participation in the creative process*; (c) *use of generative elements to evoke surprise and provoke user reactions*; and (d) *integration of applied research and production methods from art, design and technology-based fields*.

2.1.1. NEW MEDIA ART RESEARCH IN PERVASIVE COMPUTING

Because creative activities take place in a context in which interactions with other people and artifacts are essential contributors (Harrington, 1990; Mockros & Csikszentmihályi, 1999; Fischer et al., 2005), some new media artists have started to think of creativity support tools as distributed structures that mutually reinforce both individual and social creativity. This approach implies a shift from the idea of tool—or set of tools—to the notion of a socio-technical architecture deeply interwoven with the physical environment and social fabric of local communities, based on mobile and ubiquitous computing, and focused on the transmission of data and information among different interaction spaces. This line of inquiry, which we might call *pervasive creativity*, appears to be a relevant context for investigating and promoting situated and distributed aspects of creativity, particularly in relation to *temporal, spatial and conceptual distribution across multiple interaction spaces*.

INNOVATIVE CREATIVITY SUPPORT TOOL CASE #1
THE SILENCE OF THE LANDS

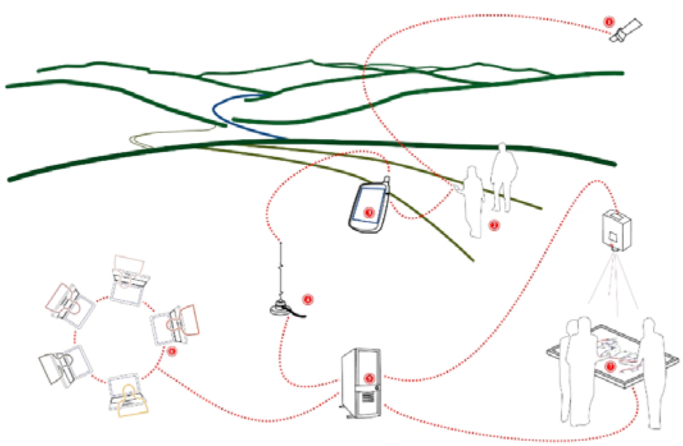


Fig. 12. Overview of the socio-technical architecture of SOL: A combination of multiple interaction spaces and social practices mediated by pervasive computing and tangible interfaces: (1) satellite (GPS signal); (2) participants (sound walks); (3) mobile interface (sound catching and geo-referencing); (4) antenna (wifi connection); (5) server (database management); (6) web interface (visualization and description of individual soundscapes); (7) tangible interface (face-to-face interaction and collective soundscape interpretation).

Developed at the Center for LifeLong Learning & Design (L3D), University of Colorado, Boulder by Elisa Giaccardi and Hal Eden in collaboration with Gianluca Sabena, Politecnico di Torino, Italy.

Case #1: Research Description

The Silence of the Lands (SOL) is a combined social game and an information-gathering tool, inspired by the vision and principles of the EDC (Arias et al., 2000) and the emerging use of pervasive computing. SOL supports the collection, interpretation, and visualization of Global Positioning Systems data that have been recorded directly from the members of a local community in order to address some of the societal problems in the definition of policies for the protection and enjoyment of natural quiet (Fig. 12). In its initial application, these data are "ambient sounds" and represent subjective interpretations of the "soundscape" of urban or natural settings that affect everyday life. By means of social participation and engagement, the project promotes a model for preservation, experience, and

renewal that empowers the active and constructive role of local communities in the process of interpretation of natural quiet. This model embodies an approach to interaction design (viz., metadesign, see Giaccardi & Fischer, 2005) as a form of cultural intervention aimed to *support creative and sustainable solutions to complex societal problems*.

SOL enables people with different, sometimes competing visions to communicate and coordinate their different knowledge and perspectives about natural quiet. This is accomplished by using sounds (rather than words) as the conversation pieces of a social game about preservation and enjoyment of natural quiet in urban or natural settings. The goal is to create a living space inside the local community by engaging participants in the recording and mapping of their own, experienced soundscape and in the construction of an idealized, virtual one. In order to support the social dialogue and the soundscapes' collaborative design, the project combines pervasive computing and tangible interfaces in a *socio-technical architecture* of disinct, but integrated interaction spaces.

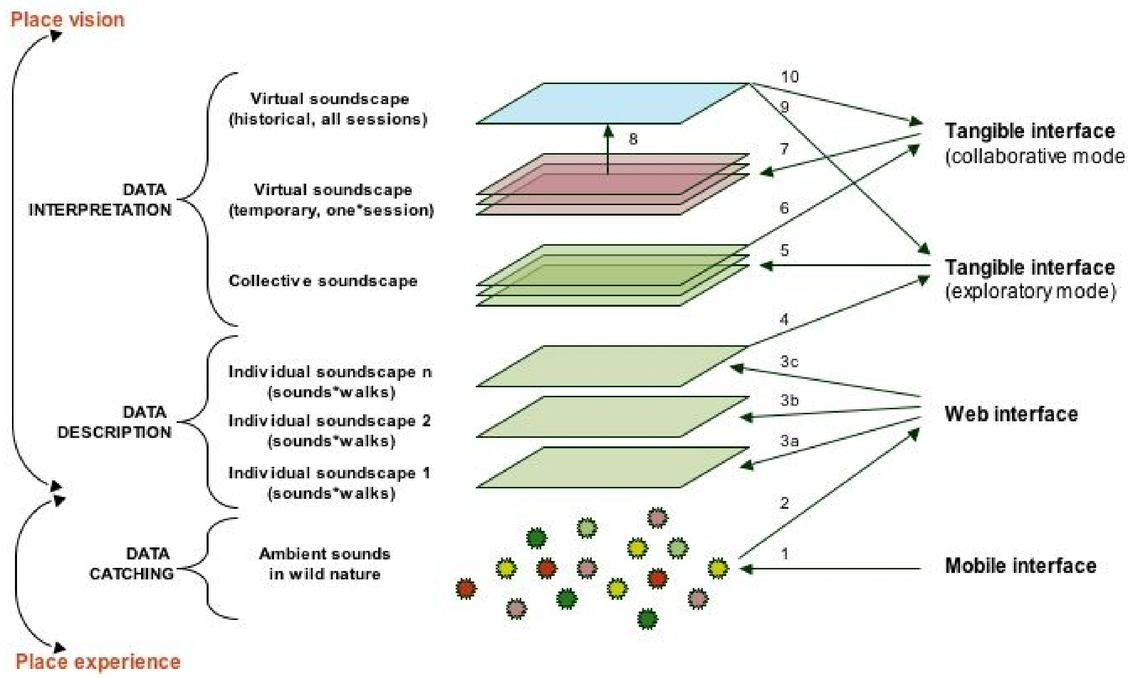


Fig. 13. Data Flow in SOL: Ambient sounds are collected from the natural environment by means of handheld devices. Each sound is linked to the user that collected it and is associated with GPS data (which determine its location in space and time). Sounds and walks (i.e. the paths followed by participants during recording sessions) are stored on the web server and visualized on the web site as individual soundscapes, one for each participant. On the web, users can access and manage their individual soundscapes (eventually modifying and changing them). They can also visualize the collective soundscape resulting and growing from the overlap of all individual soundscapes. Such a collective soundscape represents the starting point for participants in the community to collaborate on the creation of the virtual soundscape (i.e. the ideal soundscape). In the public space, both old and new participants can interact with the collective soundscape by means of tangible interfaces. Each public session produces a temporary soundscape, reflecting the understanding and creativity of the people that participated in that session. All temporary soundscapes are then composed in a historical soundscape on the basis of purposely-designed algorithms. A visualization of the historical soundscape is provided both on the web site of the project and in the public interactive space.

By providing different *entry points*, promoting the different *properties* of each interaction space, and supporting different *interaction roles* over a sustained period of time, such an architecture aims to: (a) empower the creative interaction between current and future interpretations engendered by collaborative design, (b) enable participation and collaboration that fits more naturally with existing social practices and the way in which people act and interact with their local environment, and (c) support processes of social awareness and informal learning. The collective conversation produced by the collaborative design of the participants is expected to create an "affective geography"

of natural quiet and transform such an abstract concept into a *living entity* that changes according to current and future interpretations. In this way, *The Silence of the Lands* not only increases sensitivity and social awareness about ambient sounds, but it also provides a tool for the *visualization of collective perception and public trends*.

Case #1: Design Principles

Experimental design principles for *pervasive creativity* deriving from the new media arts suggest that—in order to activate the collective stock of ideas and visions that belong to an environmental setting—tools and spaces must be woven into the existing social fabric and physical environment of the urban setting or community by means of mobile and ubiquitous computing.

The Silence of the Lands addresses the design of creativity support tools from an "ecological" perspective: that is, as a set of multiple tools and interaction spaces promoting the environmental setting as a "creative milieu" (Cliche et al., 2002) and composing a distributed, socio-technical infrastructure capable of mediating and linking the ideas, visions, people, places, production processes, and values that pertain to a specific environmental setting.

According to initial studies on public authoring (Silverston & Zoe, 2004), place-based content facilitates *memory*, *association*, and *connotation*. Furthermore, the shift from the single-desktop tool to multiple tools and interaction spaces (separated physically but seamlessly integrated virtually) promotes the *integration of individual and social creativity*. The flowing and manipulation of data throughout multiple interaction spaces (including the natural environment) enables users to promote not only spatial and temporal distribution, but also the distribution of ideas and visions (Fischer et al., 2005). Moreover, it produces what we might call *information enrichment*, that is, the engaging possibility of collecting and reinterpreting both individual and collective data over a sustained period of time, according to the different properties of the space with which a user is interacting and through which data is traveling (Fig. 13).

Case #1: Tools Development and Evaluation Methodology

This result is obtained by combining direct experience, cognitive mapping, and face-to-face interaction; that is, by combining: (a) *data catching* (individual sound collection and geo-referencing by mobile computing); (b) *data description* (individual soundscape management by web tools); and (c) *data interpretation* (collective interaction and social negotiation by tangible interfaces in a public space).

Sounds are geo-referenced and visualized on a GIS map as evolving matrices of audio objects aimed to reveal areas of dissension, consensus, and uncertainty by means of color-coded attributes and descriptors (Fig. 14 and Fig. 15).

Fig. 14 – 15. Web visualization of the collective soundscape and color-coded audio objects at different zoom levels.

2.2. NEW MEDIA ART RESEARCH IN TANGIBLE SOCIAL INTERFACES

Design thinking, which has been categorized into available design, design, and re-design, is integral to the development of meta-cognitive and meta-linguistic abilities. (New London Group, 1996) Re-design, the most transformative of the categories, supports the generation of new knowledge from current discourse by supporting the process of inquiry, discourse and negotiation. This process can be facilitated by convivial tools that enable "users to invest the world with their meaning, to enrich the environment with the fruits of their vision and to use them for the accomplishment of a purpose they have chosen" is a method by which to incorporate the transformative process of re-design (Illich, 1973). In our increasingly media-rich environment, marked by pervasive and ubiquitous computing and wireless devices, practices in new media culture are no longer limited to screen-based, audiovisual and interactive media content but address the wider social, urban and global context of the information environment, through novel approaches to process-based networked projects. Many new media artists have taken on the challenge

to design systems that foster “the diversity of the public actors and terrains and…develop strategies [for] articulating the new public domains that connect physical urban spaces and potential public sphere of electronic networks.” (Broeckmann, 2000) Convivial systems, such as the tangible social interface, encourage users to be actively engaged in computer-mediated open generative systems, designed to support intersubjective experiences that encourage, provoke and support debate, discussion for the construction of new knowledge and understanding in our shared worlds. Intersubjectivity is a theoretical concept used to understand how individuals can interact and produce consensual interpretations about a shared experience which can be other people, objects, or events (Thompson, 2001).

INNOVATIVE CREATIVITY SUPPORT TOOL CASE #2
CONSTRUCTED NARRATIVES

Principle Investigator: Pamela Jennings, Assistant Professor School of Art and the Human Computer Interaction Institute, Carnegie Mellon University.

Fig. 16.Potential target user audience for the Constructed Narratives project in an airport waiting lounge , Zurich, Switzerland. Fig. 17. Demonstration of the Constructed Narratives project at the Kiasma Museum for Contemporary Art in Helsinki, Finland 2004.

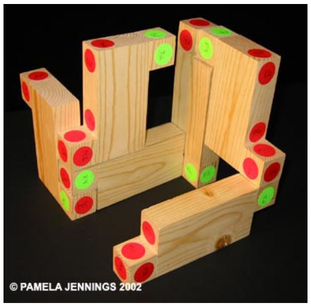
Case #2: Research Description

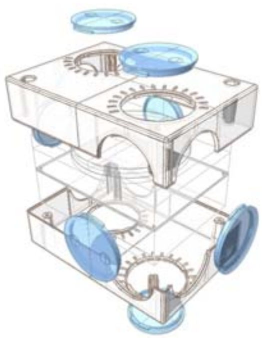
The Constructed Narratives project is a tangible social interface (TSI) – a physical interface designed to enable users to collaboratively construct and negotiate their social and knowledge networks based upon their unique preferences and user profiles. This on-going project is comprised of a set of physical blocks that when connected form an open topology network. Construction patterns in the emerging collaboratively built structure are tracked and analyzed. This analysis is used to seed a search for text which is revealed in a 3D screen-based navigable replica of the physical structure. The collaboratively built construction is a socio-technical architecture, similar in goals to projects described earlier in this document, built from the development and repurposing of information technologies to explore physical environments and the social networks among people they support. This computer supported collaborative play project is being designed for public spaces to enable dialogue between builders (users) in environments where such communicative acts are less likely to occur. The project, and overall research inquiry, was inspired by the principle investigators countless hours watching people watch people in international airports and wondering how information technologies could be used to make communicative connections between people who are co-located in a public space. Though inspired by airports, the project is envisioned for any public space where a large number of people are facilitated -- from an informal science center to a Cineplex.

Constructed Narratives is a platform being developed as a common-ground mediator that incorporates play and problem solving as a means for enhancing informal learning and knowledge networking in situations or about relational topics between participants that are unlikely to happen without a mediator to prompt contact. A key principle for learning, as articulated by the National Research Council Committee on Developments in the Science of Learning, is the ability for an individual “to engage in the mental work of making inferences,” as a means to make relationships between available information for resolving an inquiry, problem, or task. (Bransford & Brown, 1999) The Constructed Narratives system prompts the builder to incorporate inferential problem solving techniques to understand and manipulate the relationships between the physical construction and the text output. The builders’ actions of arranging and rearranging the physical blocks artifacts supports a process of empowerment where the builder negotiates structural solutions simultaneously with her collaborator and the topic of discussion as revealed through the semantic layer. The builders are co-constructing a world in which they have ultimate design authority. This is a world in which they are the very material of which that that world is made. Topics of discussion are prompted by a text layer to the construction made visible in a 3D navigable screen-projection of the physical construction. The semantic layer is determined by an underlying software engine that examines in real-time the emerging construction, ownership of the blocks and a few simple questions each builder answers prior to game play. Topics of the semantic layer include the relationship of each builder to other’s at the construction table, (e.g. self-identity, origins, environments of work and play and belief constructs,) or a domain specific topic such as environmental science, issues and their relationships to communities familiar to the builders.

Case #2: Design Principles

The design of the *Constructed Narratives* block is based on George Stiny's shape grammars, a computational design methodology. Stiny's was greatly influenced by Froebel's Kindergarten Gifts philosophy of learning through play for his design methodology. *Constructed Narratives* also references and a lineage of research based on the work of Architect Jonathon Frazer and his *Universal Constructor* generative system. (Stiny 1980, Frazer, 1995; Jennings, 2005b) The *Constructed Narratives* research project was developed by a team of Carnegie Mellon University students from eight schools on campus including the School of Art, Human Computer Interaction Institute, Electrical and Computer Engineering, Computer Science, School of Drama, School of Design, Cognitive Science, and Information Systems Management. Working on this project continues to be an interdisciplinary and collaborative effort requiring each research team member to quickly become adept with negotiating their discipline specific knowledge-base while learning new technology platforms for the development of the system. Several types of boundary objects have been used as tangible aids in the exploration of ideas and development of system solutions, as illustrated in figure 18 -21. As Gerhard Fischer has noted in his research, the boundary object is a mediator that enables the exploitation of problem solving opportunities afforded by the "symmetry of ignorance" in an interdisciplinary research team (Fischer, 1999). They provide a means to support dialogue between team members who may not be accustomed to the discipline specific language of other team members.






A selection of boundary objects used for the design and development of the Constructed Narratives blocks, hardware and software systems.
Fig.18.First wood block boundary objects used to understand computational implications inherent in the block shape grammar design;
Fig. 19. Cardboard prototype used for design and development;
Fig. 20 & 21. CAD design of the block using stereolithography rapid prototyping methods.

Development concepts from extreme programming have been used not only for software design, but experience, artifact and hardware design. Multiple iterations of sketches, scaled drawings and physical models led to the design of the *Constructed Narratives* block. The fluidity of this process enabled us to draw upon the technique that could best answer the design or development question of the moment. Simple drawings and quick cardboard mockups were the most useful in aiding the brainstorming process. A set of cardboard prototypes became an indispensable boundary object for project development across form factor, hardware, and software and experience design issues. Over time, various protocol system codes were etched on the cardboard prototypes for understanding the complex dynamic network. These cardboard prototypes with layers of penciled in notes served as crucial guides for designing and testing the integrity of the software and hardware systems. The development of scaled drawings with exact measurements and scaled physical models were important to the integration of hardware components. Functional and aesthetic design requirements were negotiated through iterative brainstorming and experimentation that supported a process of adding, substituting and removing design elements to invent an optimized solution. Circuit board diagrams of various fidelities where drawn by hand and computer aided programs to understand the theoretical and applied functions of internal circuits. Whiteboards and electronic reports and updated API files were used to develop complex software communication protocols and the relationships of those protocols to hardware and block form factor design (Jennings, 2005a).

Case #2: Tools Development and Evaluation Methodology

The boundary objects mentioned above have lead to the first iterative development of the Constructed Narratives hardware and software interface. The system is divided into four development areas including experience, tangible interface, and hardware and software architecture design to create an open-topology network that tracks emerging

collaborative design patterns and the identification of the builder who is responsible for the placement of each block in the construction in real-time.

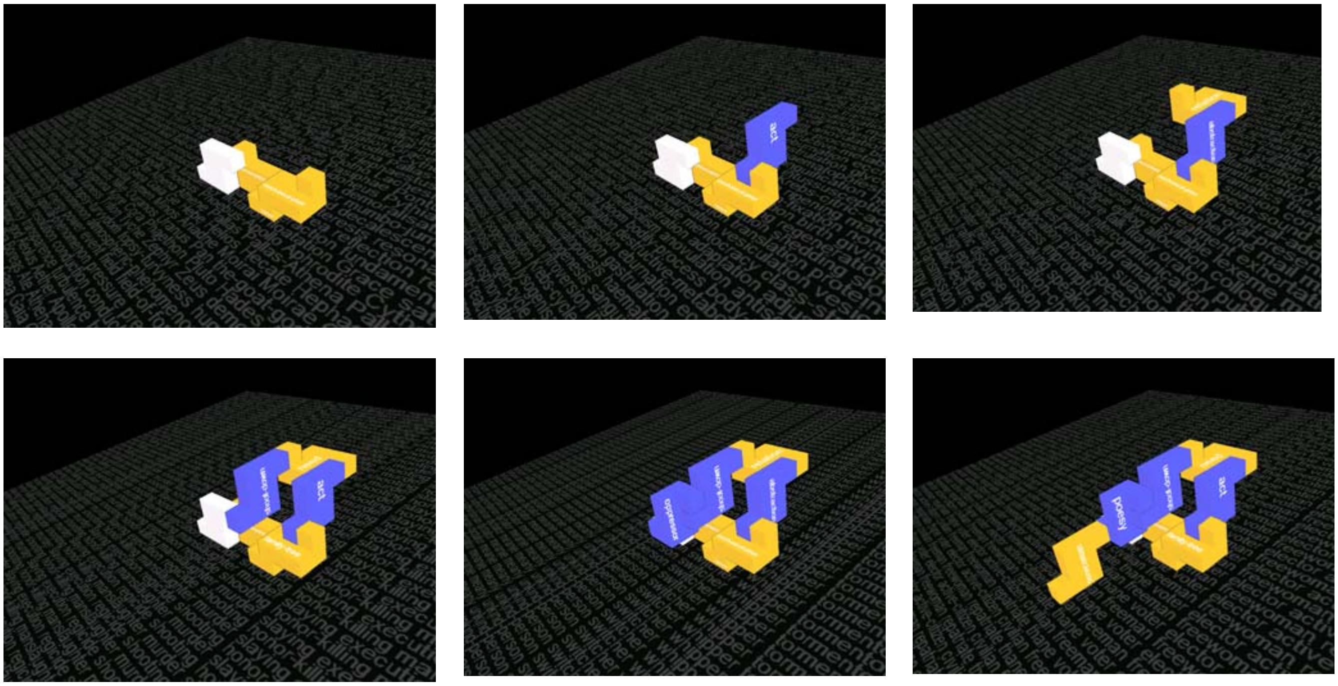


Figure 23 – 27. Screen images from the Constructed Narratives real time Virtual Build Application. The series of images show a progressive construction with the physical blocks recorded and mirrored in a navigable virtual environment. Recognized patterns in the physical construction are found by the pattern search engine. The pattern data is used to form the parameters for a semantic search in a computer based lexicon of the English language. The found words are printed onto the blocks in the virtual environment.

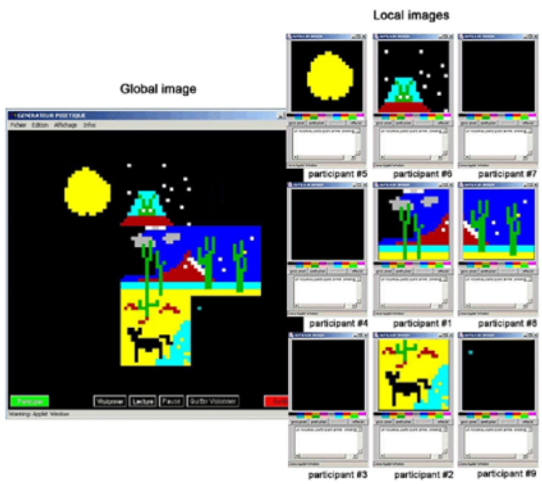
The software architecture includes the system interfaces and communication protocol between the tangible interfaces and database resources from the builder's profile application; the host application which keeps a dynamic graph of all data as the construction emerges; the semantic engine which applies a series of rules and iterative searches to find recognized patterns in the data that is used to define the type of word search to perform a linked lexicon of the English language, and the virtual build application which is responsible for printing the results into a 3D real-time navigable environment. The design of the tangible block interface and enabling hardware has also been an articulated process for the design of an open-topology twisted pair network with a block interface that has 40 degrees of freedom for possible connection surfaces. A pattern search optimization algorithm was developed to prioritize search effort and reduce search times to an acceptable response rate for a real-time interactive feedback.

2.3. NEW MEDIA RESEARCH IN COLLABORATIVE SCREEN-BASED APPLICATIONS

Emotion and context aware interaction is particularly important for the development and nourishing of co-creative activities among the participants in a collaborative application. Main motivational paths to co-creative activities—i.e. activities in which the construction and sharing of personally meaningful artifacts among participants is the creative result of a collective process—are emotionally driven, and often such activities are engendered by the context and collection of interactions among participants that are molded without any central guidance toward specific objectives or determined strategies (Giaccardi, 2005). This line of inquiry, which we might call *affective creativity*, appears to be a relevant context for investigating and promoting the emotional aspects of creativity not only in the framework of the creative practices, but also in relation to the development of creativity support tools for domains that exhibit a high degree of task uncertainty and self-organization, like for example the humanities (Pejtersen, 1980). Studies on collaborative applications for screen-based visual interaction (Giaccardi, 2004; Giaccardi, 2005) have revealed some design principles and interface features for affective creativity that are based primarily on a shift in how time, space, and environment excitations are perceived by users.

INNOVATIVE CREATIVITY SUPPORT TOOL CASE #3
POIETIC GENERATOR AND OPEN STUDIO

The Poietic Generator and Open Studio represent instances of collaborative applications for screen-based visual interaction that exemplify, by means of different interface features, the same general principles for affective creativity.



Olivier Auber, Poietic Generator (1997-2005):
Fig. 28. Local images (on the right) and resulting global image (on the left).
Fig. 29. Some results of visual interaction.

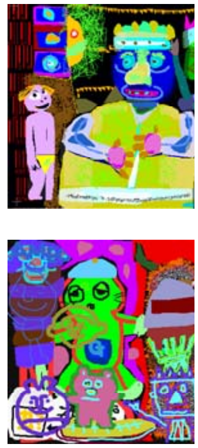
Case #3:
Research Description

The **Poietic Generator** (http://poietic-generator.net) is a distributed application by Olivier Auber. Its title refers to the idea of "poiesis", which, according to Plato in the Symposium, converts anything that we consider from non-being to being. In practice, the Poietic Generator enables a large number of people across the world to participate in real time in the emergence of an ephemeral and ever-changing image. This virtual image is the result of many local images, which are adjoining and do not overlap. Participants can join or leave the collective drawing process at any time; each new connection or disconnection causes the automatic rescaling of all the local images contained in the resulting global one. Once launched, the program continuously offers a double view of the drawing process (Fig. 28). The first view shows the current state of the global image, and it is the same for each participant. The second view shows each participant an enlargement of the local image associated with him or her. Both the abstract and minimalist character of individual signs (reduced to the scale of pixels) and the non-imposition of definite forms of expression or narrative force participants' subjective interpretation to high levels of dynamism. Collective interaction produces here an uninterrupted sequence of abstract or figurative shapes that can be observed and modified at will by any of the participants, but not globally controlled (Fig. 29).

Open Studio (http://draw.artcontext.net/) is a Java-based drawing system by Andy Deck that concurrently links users up to a single pictorial surface, and allows them to participate in the creation of a graphic animation (Fig. 30). Once connected, participants can choose whether to start interacting from scratch, by drawing on the surface of Open Studio in its current state, or to retrace the older, archived drawings. Anything a participant plays, draws, or edits on his or her applet surface is automatically shared by the other participants and added to the history of Open Studio (Fig. 31).

These various opportunities of interaction produce multiple and overlapped spaces of real and recorded time. Because it is impossible to identify one participant from another only on the basis of his or her drawing activity, the user does not know whether the strokes and marks appearing on the canvas are recorded or drawn in real time. Some participants will be "real" and some will be rather "phantoms". However, regardless of when the action took place, drawing tools have been designed to be expressive and reactive to participants' movements (speed, direction, curving, and so on). Lines, marks, and strokes convey a persistent visual and "bodily" quality that questions the nature of participants' presence, and time linearity as well.

Case #3: Design Principles



Andy Deck, Open Studio (1999):
Fig. 30. View of the tools and canvas shared by all the participants.
Fig. 31. Some results of visual interaction.

Experimental design principles for *affective creativity* deriving from the new media arts suggest that—in order to support context and emotion aware interaction and induce co-creative activities—the computational environment must enable the dynamic embodiment of users' activities and intentions. This means, for example, that in the Poietic Generator and Open Studio a user's embodiment does not take place through the figurative representation of a user's body (e.g. an emoticon or an anthropomorphic avatar), but as a visualization of participants' spontaneous activities. As indicated by Albrechtsen et al. (Albrechtsen et al., 2001), an understanding of embodiment in terms of direct perception-action in the graphical interface is particularly important for "loosely coupled domains", i.e. domains characterized by "a high degree of task uncertainty" and "a high degree of freedom and diversity of cognitive control among the actors involved" (viz. self-organization) like, for instance, hospitals and libraries.

In the cases presented here, the visual embodiment supported by the Poietic Generator and Open Studio enables users to experience the computational environment as both the world in which they can manifest and express themselves and also a source of sensory-motor and emotional excitations. Their embodiment in the computational environment takes the form of the visual language performed to express themselves and communicate with each other: their body is defined by the way in which their manifest themselves through the use of marks, colors, and other different kinds of visual elements. For example, the local image in the Poietic Generator, or the individual painting in Open Studio, constitutes the contours of a users' body. However, it is only by acting and reacting, affecting the others and in turn being affected by the visual events produced by other participants, that users manifest themselves and identify meaningful structures. Such a relational setting provides a social and dynamic context for the evolution of the interaction process that allows participants to spontaneously negotiate their common goals and creative processes.
Design principles for affective creativity can be summarized as following (Giaccardi, 2005):

- Space must be perceived and experienced as a *proximal field* (interface features must be designed for people to interact with each other in a "physical" and "intimate" way, rather than simply to locate them in the same or a different place);
- Time must be perceived and experienced as a *network of intentionalities* (interface features must be designed for people to determine and recognize chains of actions and meaningful events over time, rather than simply to define whether they are interacting synchronously or asynchronously);
- Spatial and temporal interface features together must enable the formation of *affective bodies* (flexible representations defined by the ways in which users manifest themselves) and *relational settings* (environments where actions are embodied by these representations);
- The interplay between the opportunities for action provided by the information system and the external representations of cognitive activities carried out by means of the system must support the emergence of environment excitations collectively interpreted as *meaningful structures* through loops of perception and action among participants. See (Giaccardi, 2005) for a conceptualization of affordance, externalization and mediator in this context.

Case #3: Tools Development and Evaluation Methodology
Generally speaking, the questions raised by these applications can be summarized in: (a) can embodiment—intended not as the presence of agent-like characters on the screen, but as the level of our interdependency in perception and action with the world mediated by the tool (as just described in the Poietic Generator and Open Studio)—be the measure of a "creative milieu"? Can engagement—intended as our level of activity and motivation—be a measure of creative performance? The answers come from a phenomenon-based approach, grounded on the integration of

different kind of data and descriptions (objective, subjective and empathic) as suggested by Francisco Varela and his colleagues (Varela & Shear, 1999; Roy et al., 1998). Such a methodology has been applied in the evaluation of the Poietic Generator and Open Studio as creativity support tools (Giaccardi, 2004; Giaccardi, 2005) and has produced the identification of above mentioned design principles.

3. Policy Making and the New Media Arts: Promoting Technology Development, Cultural Development, and the Sustainability of Micro-Economies

The potential legacy and impact of new media arts on cultural development and local micro-economies (Florida, 2005) is being recognized by both creative industries and non-profit organizations. During the past decade, several initiatives in the form of international research collaborations, interdisciplinary symposiums and conferences, and new government and foundation sponsored funding opportunities have been recognizing the important role that creativity, and in particular arts driven creativity, plays in the development of new technologies and information rich applications (Makela, et.al, 2004; Mitchell, 2003; Jennings, 2000).

In light of contemporary creative practices, policy-making has revised the notion of artistic creativity. Even though artistic creativity is usually described as a rules-breaking process leading to innovative visions of the individual artists, the focus is shifting to recognize the diverse and sustainable collective stock of "intangible assets" ("creative milieu") that are created by artists and arts collectives influencing and changing the way in which the greater society incorporates information technology tools in the daily work, play, and educational activities. (Cliche et al. 2002)

The progressive approaches to policy-making in several of the initiatives listed in the appendix of this paper, the "Helsinki Agenda: Strategy Document on International Development of New Media Culture Policy." and listed elsewhere in the Creativity Support Tools report have been designed to support and nourish with sufficient infrastructure the environmental settings and resources compatible to STEM based initiatives to support the development of creative innovation in the new media arts research-in-practice. (Makela, et.al. 2004; See the Helsinki Agenda principles in appendix A).

Conclusions

New media artists are not only "creative people", intended as users of tools capable of producing creative work ("people that do creative things"). Often artists, as well as scientists, are also the creators of their own tools. In the case of the new media arts, they are the designers of creativity support tools for others to engage in an interactive experience or be originally creative in the production of a "co-authored" work. The same pattern of developing innovative interfaces for others to use can be found in other practices or disciplines, and new media arts add a piece to the big picture of how to develop support tools for the multiple forms of individual and social creativity expressed in different domains.

We encourage the HCI and software engineering community to look at new media artists not only as consumers but also as peers, and to treasure their potential contribution by establishing a thoughtful and vibrant dialogue, aimed to create long-term support for:

1. Transdisciplinary educational programs focused on technology and science inquiry and innovation through creative practice;
2. Experimental processes and practices in the new media arts that relate to the public space, discourse, and development of new technologies, tools, and transdisciplinary knowledge;
3. Research networks bringing together local, regional and global constituents (individuals, organizations, funding agencies, corporations, etc.) to share information, form alliances, and develop best practices in new media arts research.

APPENDIX

A. The Helsinki Agenda principles

1. Art practice and research in new media is a key generator of new knowledge in arts, science, technology, communication and education.
2. Art practice and research in new media inform the dialogue between practitioners, researchers, creative industries and the public.
3. New media practices have developed forms and protocols of knowledge sharing and access based on principles of openness, collaboration and creative freedom.
4. New media practitioners can revitalize museums, archives and other heritage contents by allowing for greater public access, public renditions and imaginative readings.

5. New media artists create transformative cultural experiences that inspire communities and individuals and expand the scope of creative industries and technology development.
6. New media cultural practice informs larger social policies. By enabling and establishing deeper, as well as more pervasive modes of contemporary communication systems these practices lead to richer possibilities of social, inter-generational and inter-cultural communication, participation and access in our increasingly complex and multi-cultural societies.

B. International new media arts funding policy initiatives

Canada

- **Image, Text, Sound, Technology Strategic Grant (ITST)**
  Social Sciences and Humanities Research council of Canada Supports new media initiatives that are networks, consortia or conferences and workshops
- **Canada Council with Natural Sciences and Engineering Research Council**
  Provides research funding for joint initiatives by new media artists and scientists juried through both councils.
- **National Research Council (NRC) Artists-in-Residency program**
  Places artists into the NRC's extensive laboratory system for two year research and creation experience
- **CANARIE Applied Research in Interactive Media (ARIM)**
  http://www.canarie.ca/funding/arim/guidelines.html
  Supports innovative, collaborations amongst participating organizations, focus on areas of advanced networking such as grid computing, a method of using resources distributed across a network to create the tools that allow a community of users to share network based cultural expression and experiences.
- **Hexagram**
  http://www.hexagram.org/spip/index_en.php3
  The mission of Hexagram is to promote and support research, creation and transfer in media arts and technologies. The challenge is stimulating since the goal is to build a real bridge between artist/researchers and users.

United Kingdom

- **Arts and Science Research Fellowships**
  www.interdisciplinary.org.uk
  Fellowships for artists collaboration with science and technology researchers
- **Engineering and Physical Science Research Council** programs support artistic engagement with technology
- **NESTA (National Endowment for Science Technology and the Arts)**
  www.nesta.org.uk/insidenestal/hwf_learning.html
  Lottery money allocated to support talented individuals working in innovative ways; 500 new media projects funded.

Australia

- **Australia Network for Art and Technology**
  http://www.anat.org.au/
  Scientific Serendipity initiative jointly supported by Australia Council and Department of Industry Science and Technology
- **Synapse Strategy** www.synapse.net.au
  ANAT, ARC, university research centers, Commonwealth Science and Industrial Research Organization (CSIRO) and industry engage the nexus between art and science at the very point where these collaborations fuse complex social and political issues of the 21st century.

Netherlands

- **Virtual Platform**
  http://www.virtueelplatform.nl/article-1024.86.html
  The Virtual Platform is a network for policy and cooperation in the field of new media and 'living culture' in the Netherlands. Its aim is to further the free development and application of ICT and free access to ICT within culture in general and in the arts in particular.

International

- **UNESCO 2004 Digital Art Award** http://portal.unesco.org/culture/en/ev.php-URL_ID=22405&URL_DO=DO_TOPIC&URL_SECTION=201.html
  Aims to promote digital art as an innovative and artistic reflection on the information society. It forms a special category of the UNESCO prize for the Promotion of the Arts, rewarding young emerging artists for outstanding creative achievements.
- **Creative Crossings** http://www.elasticspace.com/2004/04/creative-crossings
  Arts Council England, m-cult Finland, Banff Centre for the Arts, Canada to support Canadian, UK and Finnish artists, researchers, technologist who are exploring issues of ethics, meta data structure, cultural analysis, participatory design, creating alternate modalities and methods in wireless applications.

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Supporting Creativity with Search Tools

Bill Kules, University of Maryland

Introduction

Is searching creative? Searching and information seeking are part of the creative process. An architect looking for "seed" ideas for a new project may search an architecture database. Novelists, journalists and artists may similarly search the web for new ideas. A historian will explore archival material for a research project. Even graduate students may employ search as they refine and narrow their research topic. Information seeking models of the writing process acknowledge the creative elements, identifying specific stages for topic exploration and formation (Kuhlthau, 1992). Advertising art directors search for images as part of their creative process (Garber & Grunes, 1992). Engineers and software developers search for creative solutions to technical problems, too.

Developers of search tools have traditionally focused on searches in which the objective is clearly defined, such as known-item or fact searches. Typical web search engines and databases are now very effective at satisfying these searches with a simple ranked list of results. In the context of a creative task, however, the information need may be only partially specified or ambiguous, and the searcher may not be familiar with terminology in the domain or collection being searched.

Four kinds of information have been proposed as aiding the creative process (Bawden, 1986): Interdisciplinary information, peripheral information, speculative information, and exceptions and inconsistencies. Creative searches can embody (at least) the following four characteristics. Within the characteristics we propose techniques that may support creative search by helping searchers encounter these types of information:

- Generative goals – Rather than finding a specific document or fact, the goal of the search can be to learn about a topic area, develop a question, generate ideas, identify unusual items ("outliers") or even look for conflict or inconsistency. Queries may be ambiguous or partially defined.
    - Meaningful and stable categories
    - Variable categories, including clustering/clustered overviews
- Cross-context – Searches may extend across domains or collections. Indeed the searcher may deliberately search in unfamiliar domains to gain alternative perspectives on a topic or discover previously unnoticed connections.
    - Literature visualization
    - Literature linking
- Exploratory and iterative – Searchers interactively explore the search results by browsing, filtering or other techniques. They issue multiple, successive queries as their information need evolves, possibly across multiple sessions. They exhibit "berry-picking" or "information foraging" behavior as they collect useful bits of information, follow promising threads and identify new information sources.
    - History mechanisms
    - Workspaces
    - Enhanced bookmarks

- Serendipity, non-linearity – Serendipitious findings can provide valuable insight for the creative searcher

Because of the variety of creative tasks, this list is certainly incomplete, and no single task is likely to embody all characteristics.

Review of Search Interfaces

This section considers the first two bullets and illustrates features that we propose will support creative search. For a more comprehensive review of search visualization interfaces, see Hearst (1999).

1.1. Ranked Search Results

Typical web search engines are optimized to support known item and fact search by ranking documents according to query relevance, link analysis, popularity or combinations of several metrics. Google does provide a link to "similar pages," which allows users to quickly find documents that satisfy a similarity metric.

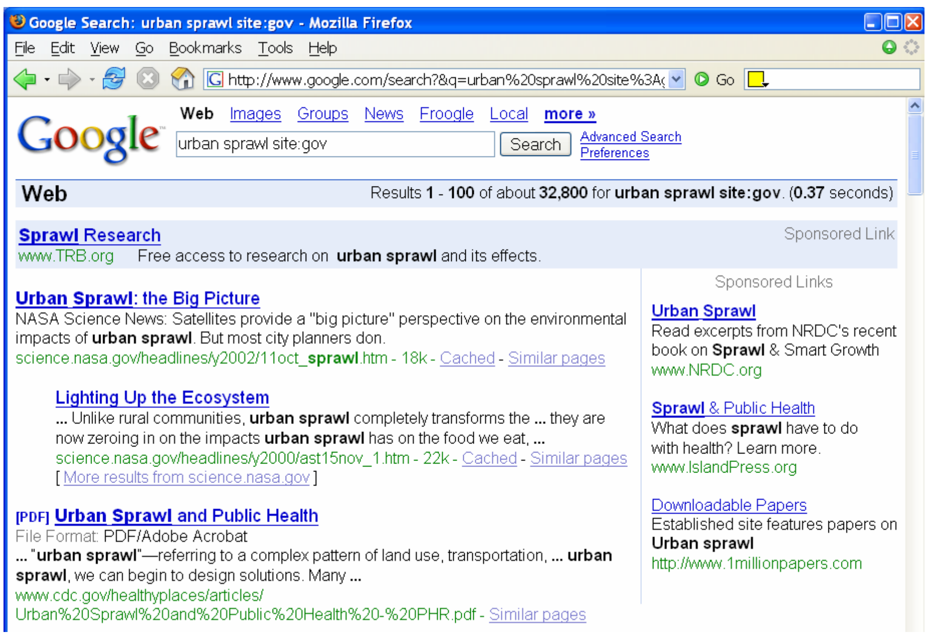

Figure 1. The Google interface shows the top search results for the query "urban sprawl site:gov" as a ranked list (www.google.com).

1.2. Organizing by Meaningful and Stable Categories

Interactive overviews of categorized web search results using meaningful and stable classifications can support user exploration, understanding of large result sets, and discovery. The categories can be drawn from large thesauri, glossaries, or ontologies. Alternatively, they can be based on simple categorization schemes such as document type, country codes or ranges of document size. They support the "search and browse" process that is typical of exploratory searches by providing a consistent organizing structure for keyword searches. When used to filter ranked search results (Figure 2), users found pages of interest deeper within the results and noticed more unexpectedly missing results – that is categories with no associated results – compared to a control interface (Kules & Shneiderman, submitted).

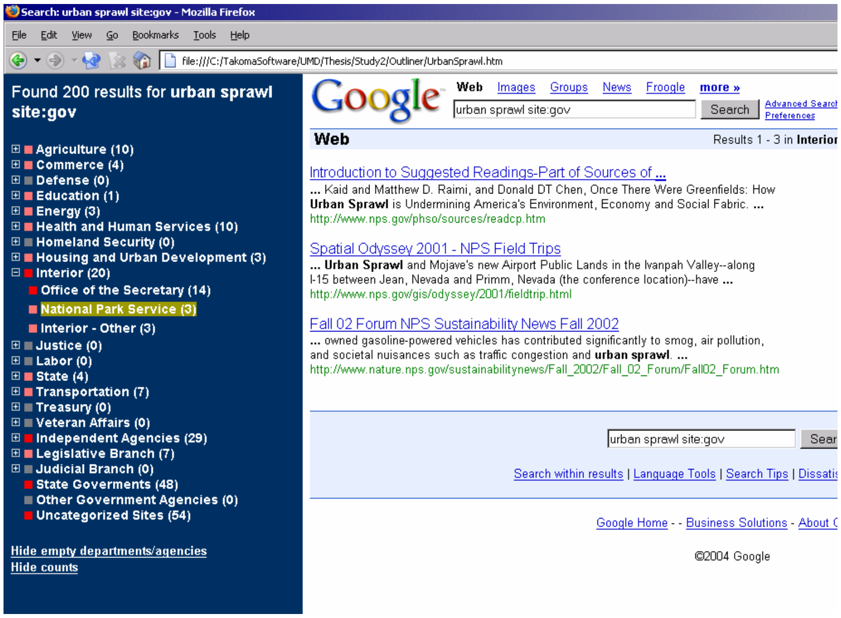

Figure 2. This overview+detail interface shows the top 200 results for the query "urban sprawl site:gov." They have been categorized into a two-level government hierarchy, which is used to present a categorized overview on the left. The Interior Department, which has 20 results, has been expanded and the National Park Service has been selected. The effect on the right side is to show just the three results from the Park Service (Kules & Shneiderman, submitted).

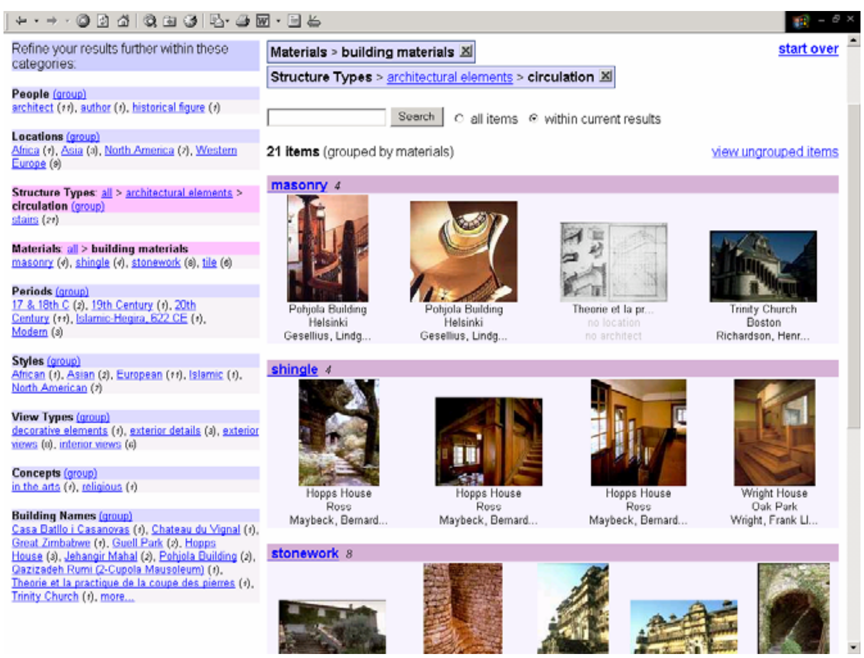

Figure 3. Flamenco uses multiple sets of hierarchical categories ("hierarchical faceted metadata") to organize guide browsing and searching. In this figure, the user has filtered architectural images to show images that represent both *building materials* and *circulation elements* (Yee, Swearingen, Li, & Hearst, 2003).

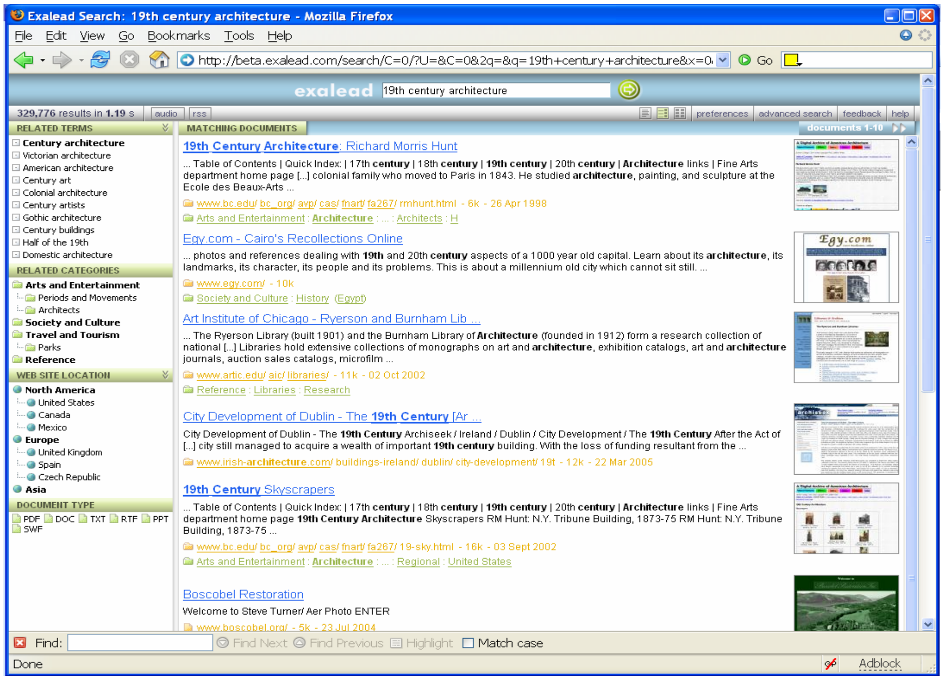

Figure 4. Exalead produces categorized overviews using topical categories as well as categories based on geography and document type. (www.exalead.com)

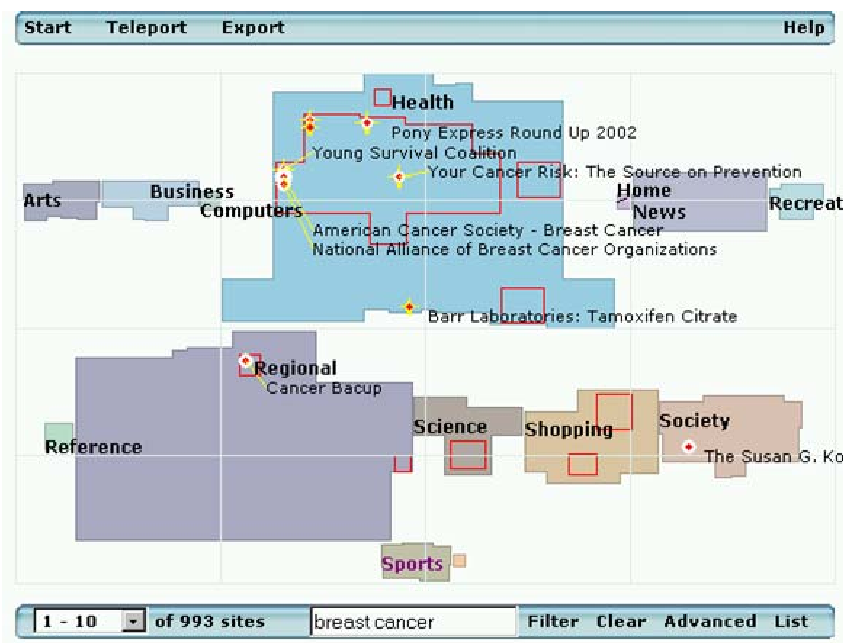

Figure 5. Antarctica uses an abstract two-dimensional map of hierarchical categories to display search results and support browsing. Here, the results of a query on "breast cancer" have been displayed. The top 10 results are plotted on the map using coded icons with titles. Users can click on a region to "zoom into" that category (www.antarcti.ca).

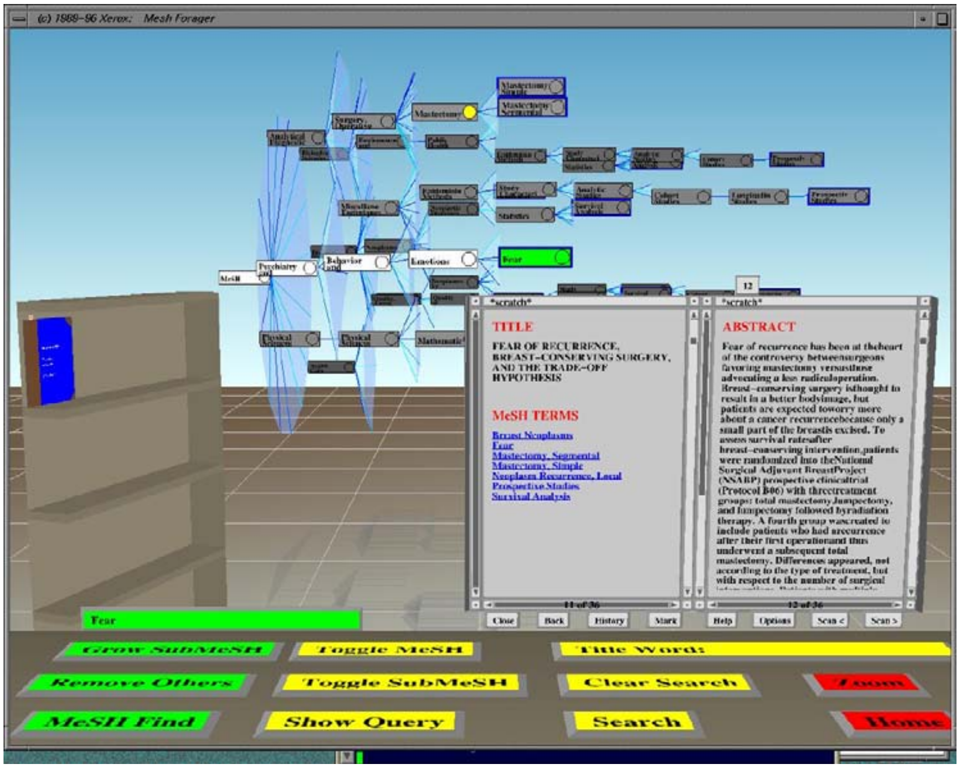

Figure 6. Cat-a-Cone supports search and browse in MeSH, a very large hierarchy of terms used to classify medical research reports. The hierarchy is displayed as a cone tree, which users can interactively navigate through. They can also issue a query, whereupon the tree is pruned to show only categories with matching documents (Hearst & Karadi, 1997).

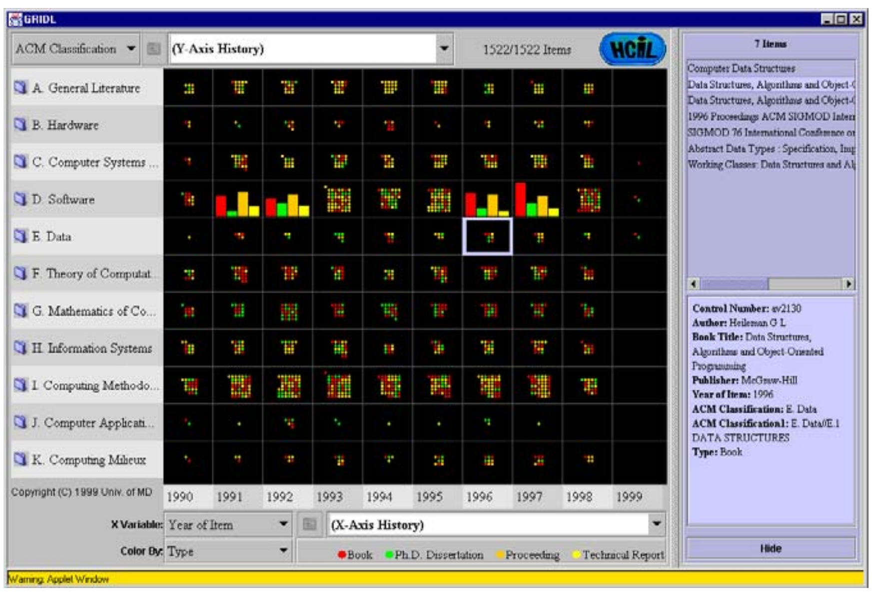

Figure 7. GRIDL uses categorical variables to organize search results on a two-dimensional grid. Here the user has organized computer science documents along according to the ACM classification (vertical) and year of publication (horizontal). At each grid point clusters of color-coded dots represent the documents and show a third attribute, the document type. If there are more than 49 documents in a grid point a bar chart summarizes the by document type. Users see the entire result set and can then click on labels to move down a level in the hierarchy.

Multiple sets of categories can be used to support conjunctive filters while retaining the benefit of stable organization, and helping users avoid feeling “lost” in the information space (English, 2002).

Categorical metadata can be represented using graphical displays. Search results can be displayed on an abstract map (a two-dimensional space) based on a hierarchy of categories (Figure 5). Three-dimensional displays have been used to visualize very large hierarchies

A matrix can be used to organize results along two categorical or numeric dimensions (Kunz, 2003; Kunz & Botsch, 2002; Shneiderman, Feldman, Rose, & Grau, 2000).

1.3. Organizing by Variable Categories

Variable categories, produced by clustering search results into dynamically generated categories, can be used in place of stable categories to produce similar displays of search results. Clustering has been found helpful for search tasks, although searchers sometimes fail to understand the clusters or their labels. Variable categories can be used in overview+detail interfaces (Figures 8 and 9) or visual maps (Figures 10 and 11).

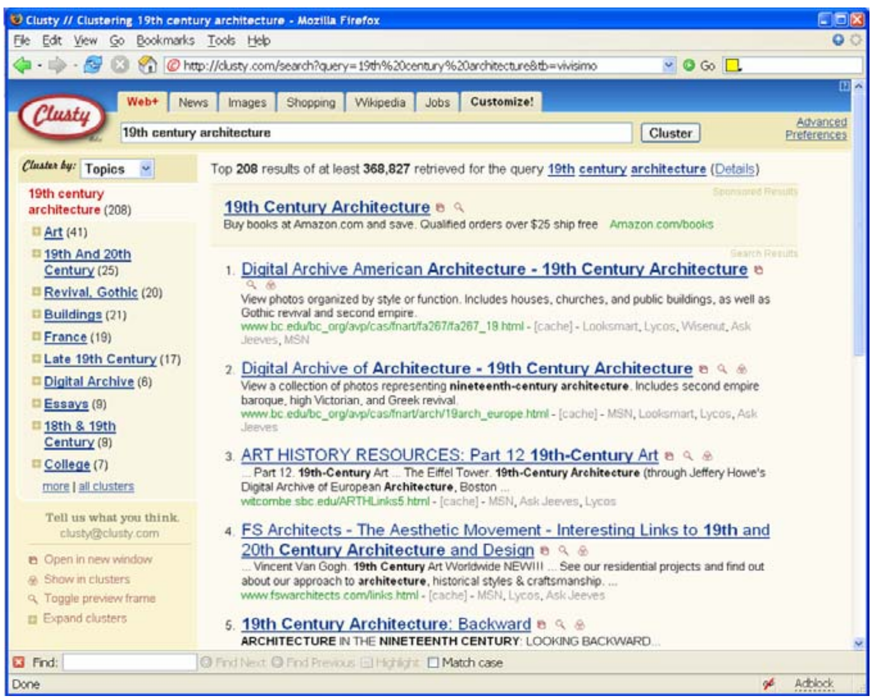

Figure 8. The metasearch engine Clusty (and its predecessor Vivisimo) uses a form of automated document clustering that generates hierarchies of concisely labeled clusters. In this example, the top 208 results have been clustered, and the cluster labels have been used to generate an overview with 10 categories initially visible. Users can show more categories or filter and navigate the results using the expandable outliner (www.clusty.com).

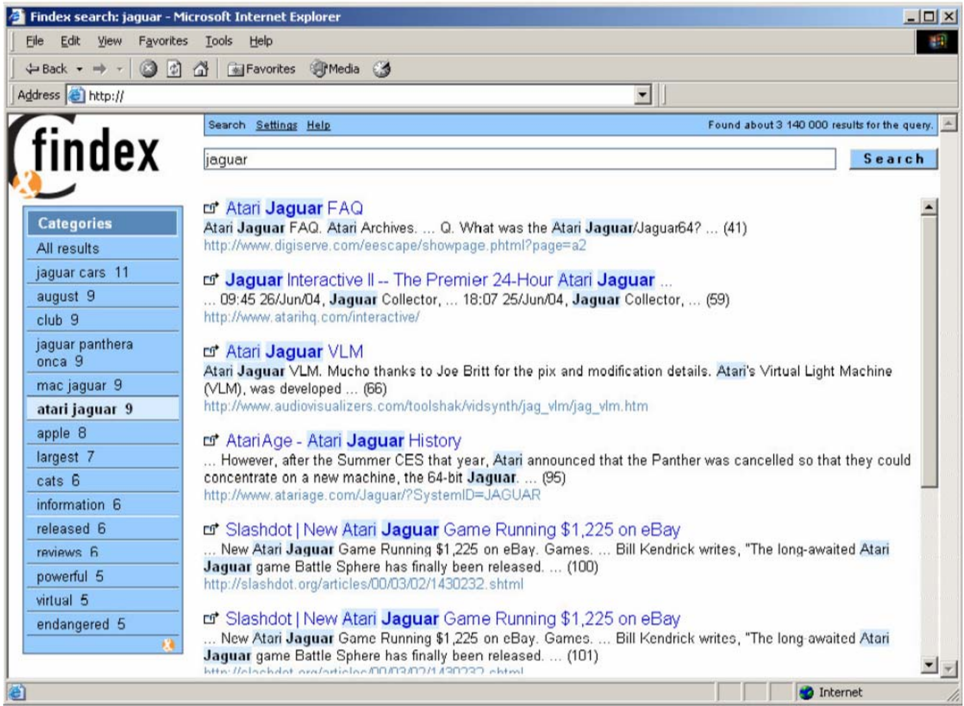

Figure 9. Findex clusters documents into a flat set of categories. Here the results from the query "jaguar" have been clustered into 15 categories. The "atari jaguar" category has been selected (Käki, 2005).

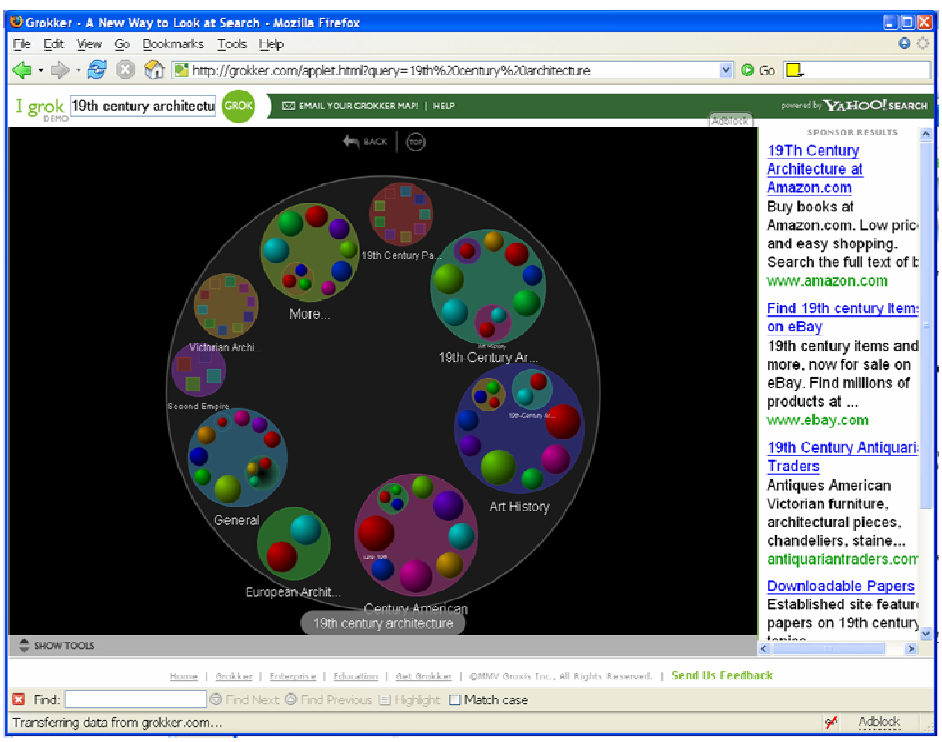

Figure 10. Grokker generates hierarchical clusters and displays those clusters using concentric circles. Users can drill down into clusters to explore the results.

Figure 11. Kartoo clusters results to produce a topical overview on the left, and displays the top 12 documents as a visual map of semantic relationships.

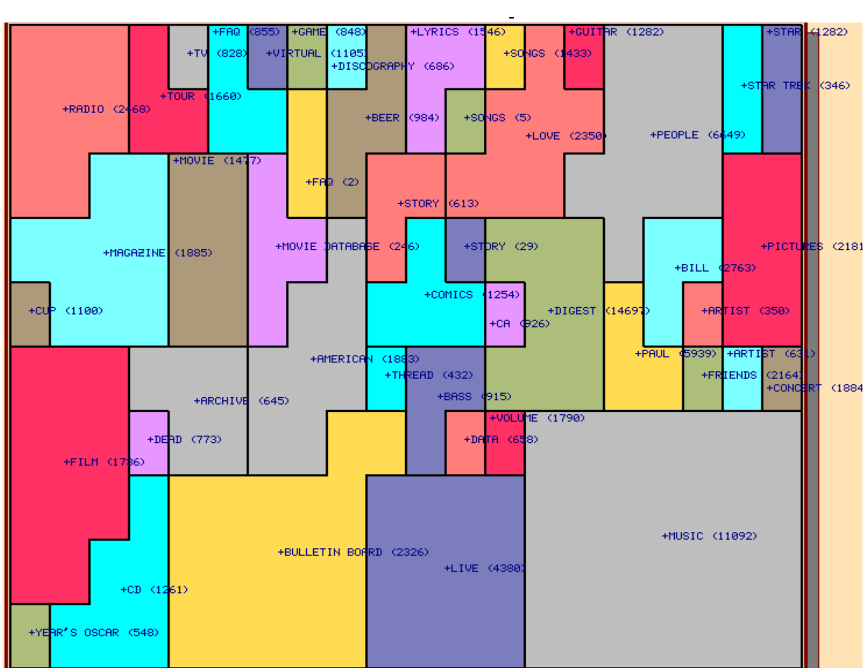

Figure 12. The ET Map is a multi-layer self-organizing map

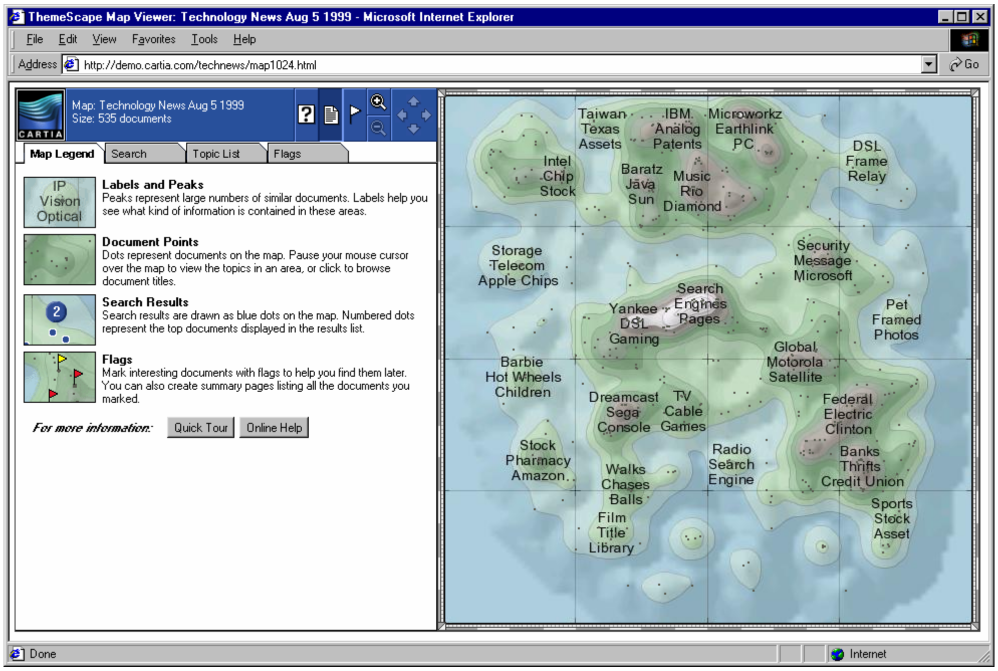

Figure 13. Themescape uses a topographc map metaphor to plot keywords extracted from a corpus.

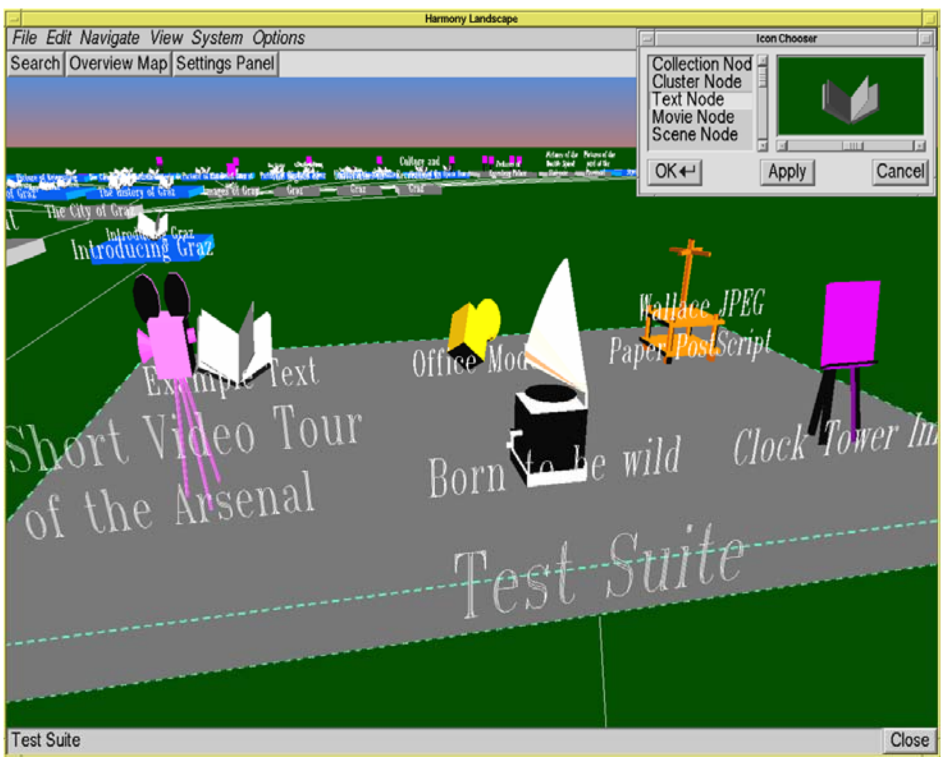

Figure 14. The Harmony Landscape visualizes an information space on a receding plane.

1.4. Literature visualization

Literature visualization tools provide overviews of a knowledge domain or field of research by visualizing bibliographic attributes such as citations between articles or common themes. Co-citation networks visualize citations between papers by significant authors in a field. They can graphically illustrate major topics and sub-fields (Chen, 1999). These maps may help searchers bridge multiple fields or identify trends.

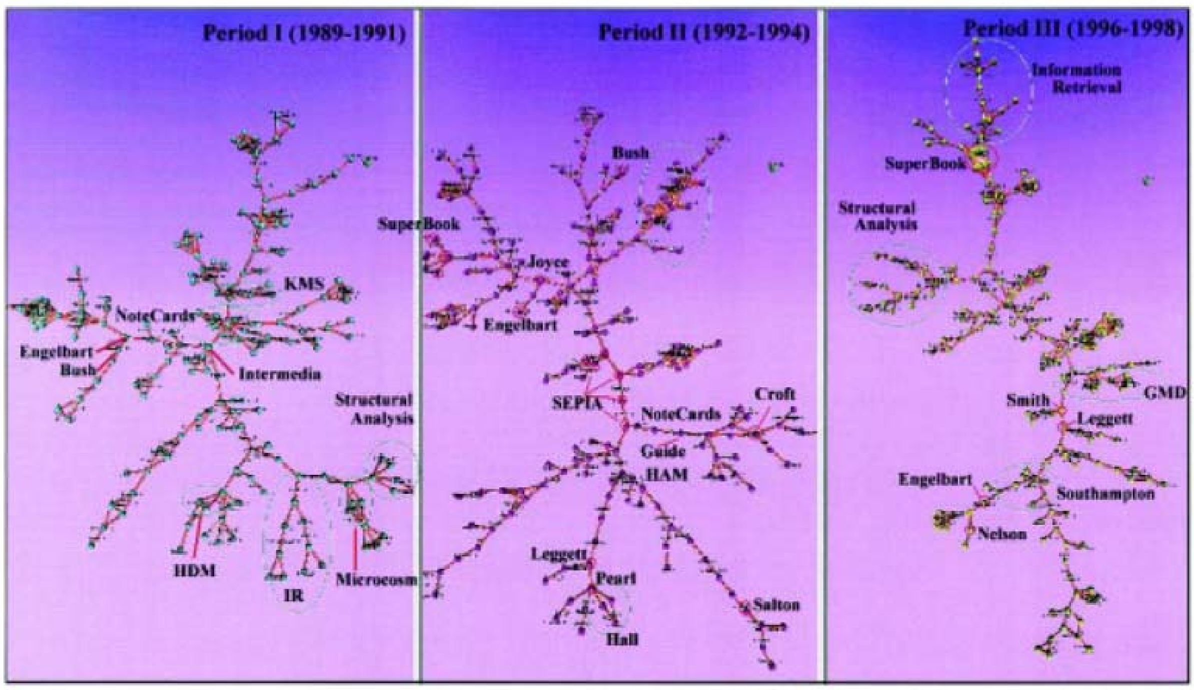

Figure 15. This co-citation map is derived from a collection of papers on hypertext. It shows three snapshots the hypertext field. Relationships between major topics and authors can be seen. (Chen, 1999)

1.5. Literature linking

Literature linking is a specialized form of creative information seeking that attempts to discover new connections between two literatures. It has been used to identify hidden connections in the medical literature between migraines and magnesium by citation analysis and manual review of terms common in both literatures (Swanson, 1988). The LitLinker system (Pratt & Yetisgen-Yildiz, 2003) is a recent example of this technique. It provides a user interface that allows searchers to select starting and target terms within a set of literatures, and interactively explore potential links.

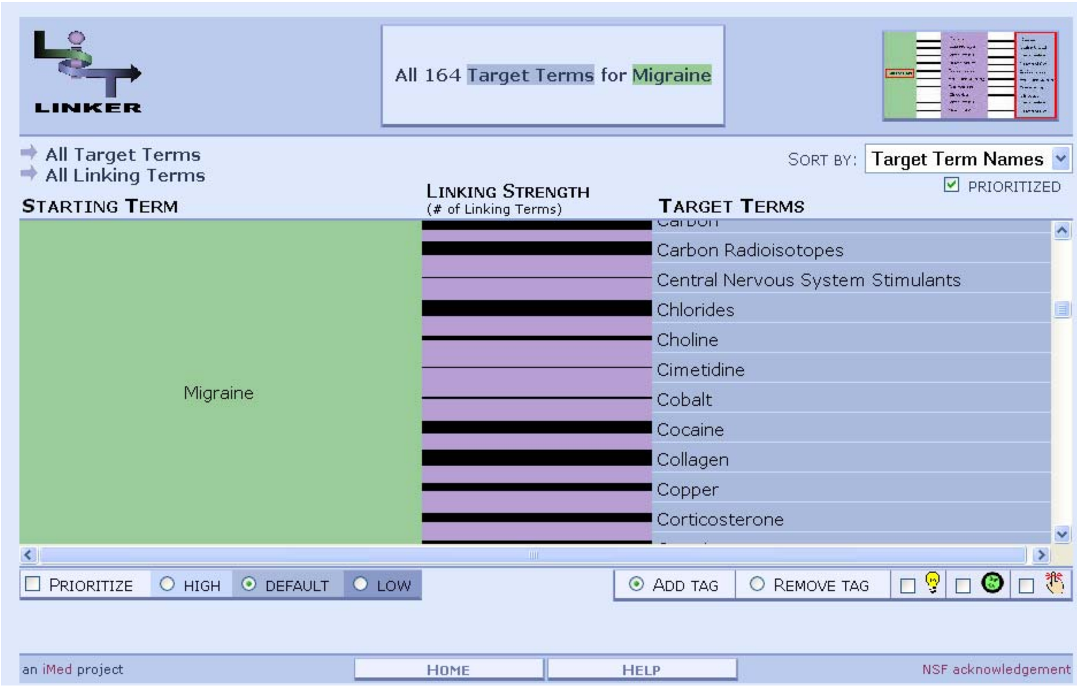

Figure 16. LitLinker (http://litlinker.ischool.washington.edu)

Conclusion

The interfaces described above may help information seekers by doing more than simply displaying ranked lists of search results – by exposing them to information that will help the creative process. The visual presentation of information has a powerful impact on what is perceived, particularly with the information visualization techniques illustrated here, and could prove to be useful tools for the creative information seeker.

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Funded Research Relevant to the Creativity Support Tools Workshop

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> The notes that follow cannot represent a comprehensive international survey. Rather, they draw on a limited number of examples in order to illuminate the current situation in initiatives to promote and support advances relating to creative capability.

Perhaps the most influential recent move that has moved the interest in funding research in creativity forward has been a concern, in certain governments for "the Creative Industries".

> "Those industries that have their origin in individual creativity, skill and talent and which have a potential for wealth and job creation through the generation and exploitation of intellectual property"

Was the definition used by a UK government initiative, the Creative Industries Task Force which was established by the Prime Minister in 1997. It concluded its work in 2000 and is succeeded by the inter-departmental Ministerial Creative Industries Strategy Group. The Task Group's main conclusions were included in the Creative Industries Mapping Document 2001, published in 2001. In the first version of the document, published in 1998, the Secretary of State, Chris Smith, said

> "Culture and Creativity are vital to our national life…But there is another justification for creativity…the creative industries generate revenues approaching £60bn a year. They contribute over 4% to the national economy and employ around one and a half million people. The sector is growing faster than, almost twice as fast as, the economy as a whole." (Creative Industries Mapping Document 1998).

These concerns have been echoed in other countries, such as Hong Kong, with its Baseline Study on Hong Kong's Creative Industries of 2003 (Central Policy Unit) or the Japanese NLI Research Institute report, SOCIOECONOMICS 2003/12/02 [The Status of Creative Industries in Japan and Policy Recommendations for Their Promotion]. In all cases, the economic importance of creativity is seen to be important and, hence, an argument for improving capability made. Recently Brazil has become committed to serve as the headquarters for an International Centre for the Creative Industries (ICCI), planned to be established by the United Nations in 2006.

In the UK, one very notable initiative was the formation of a funding body specifically charged with the task of promoting creativity, NESTA - the National Endowment for Science, Technology and the Arts, which was founded in 1998. To quote from their publicity:

> "We are funded by an endowment from the National Lottery and use the interest to back people of exceptional talent and imagination. We do our best to offer the support they need to explore new ideas, develop new products and services, or experiment with new ways of nurturing creativity in science, technology and the arts."

A number of research bodies have been working in this direction within existing remits, however. For example, again in the UK, the Engineering and Physical Sciences Research Council modified its Human Factors in Information Technology programme to include "support for creativity" as one example of what could be funded: only a small word change, but quite a significant one. This change was made following the Creativity and Cognition 2 1996 conference, which the responsible Council officer attended. The Loughborough research on the topic, COSTART, was largely funded as a result of this initiative. Of all the work mentioned in this note, this is the only research which can be said to both arise from a specific funding initiative and focus on creativity support tools and methods.

Promoting creativity, however might often be best served simply by putting creative people from different fields together.

Perhaps the most interesting specific funding opportunities have been those that brought artists and scientists, for example, together. These have included the Synapse initiative in Australia, run by the Australia Council, which is particularly interesting in how it used existing mechanisms. Synapse is funded partly by the Australian Research Council as an academic/industrial partnership. The specific arrangement made was to allow the arts funding body, the Australian Council, to count as an industrial partner. In the UK, the Arts and Humanities Research Council is funding arts science collaborations. As are A C E the Arts Council of England. The Wellcome Trust is also funding art/science projects, sciart, that bring leading scientists and artists together.

There are a number of important institutions that support collaborative research through various funding arrangements. For example, in Canada, the Banff Centre, in Austria, ARS Electronica FUTURELAB,in Germany, ZKM, the Center for Art and Media and in Hungary C3, the Center for Culture & Communication. Some of these have access to government money, others have industrial funding and many are primarily self funding. Some new media educational institutions have interesting programmes within their repertoire, for example IAMAS in Japan and UTS in Australia. From time-to-time companies have operated programmes of collaboration, such as the artist in residence scheme PAIR at Xerox PARC.

Many of the specific examples mentioned above arose from the strategic directions set as a result of realising that creativity is of economic as well as social importance. Following that understanding, much of the rest can follow.

Links:

Creative Industries Mapping Document 2001 : http://www.culture.gov.uk/global/publications/archive_2001/ci_mapping_doc_2001.htm?properties=archive%5F2001%2C%2Fcreative%5Findustries%2FQuickLinks%2Fpublications%2Fdefault%2C&month=

Creative Industries Mapping Document 1998 : http://www.culture.gov.uk/global/publications/archive_1998/Creative_Industries_Mapping_Document_1998.htm?properties=archive%5F1998%2C%2Fcreative%5Findustries%2FQuickLinks%2Fpublications%2Fdefault%2C&month=

Baseline Study on Hong Kong's Creative Industries : http://www.info.gov.hk/gia/general/200309/16/0916249.htm

Central Policy Unit: http://www.info.gov.hk/cpu/english/new.htm

SOCIOECONOMICS 2003/12/02 [The Status of Creative Industries in Japan and Policy Recommendations for Their Promotion] : http://www.nli-research.co.jp/eng/resea/life/li031202.html

(ICCI) : http://www.brazzilmag.com/content/view/2111/49/

NESTA - the National Endowment for Science, Technology and the Arts : http://www.nesta.org.uk/

Creativity and Cognition 2 : http://research.it.uts.edu.au/creative/lutchi/ccog2.html

COSTART : http://research.it.uts.edu.au/creative/COSTART/

Australia Council : http://www.ozco.gov.au/grants/other_support_new_media_arts/synapse/

Arts and Humanities Research Council : http://www.ahrc.ac.uk/news/news_pr/2004/combining_creativity.asp

A C E : http://213.130.131.21/ace/html/frames.html

sciart : http://www.wellcome.ac.uk/node2530.html

the Banff Centre : http://www.banffcentre.ca/programs/

ARS Electronica FUTURELAB : http://www.aec.at/de/futurelab/index.asp

ZKM, the Center for Art and Media : http://on1.zkm.de/zkm/e/

C3, the Center for Culture & Communication : http://www.c3.hu/c3/txt-index.html

IAMAS : http://www.iamas.ac.jp/

UTS : http://www.creativityandcognition.com/

PAIR : http://www.pair.xerox.com/

Seven Issues for Creativity Support Tool Researchers

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Introduction

Workshop participants discussed several concepts, types of practices, and aspects of human cognition as important ingredients for research on tools for supporting creativity. There were lively discussions as participants from different disciplines learned about each others' perspectives and approaches to research. We made progress in coming to a more coherent view of tools supporting creativity. This section lists seven diverse concepts that appeared repeatedly in our discussions. Although not completely woven within the research framework, these issues in some sense constitute the idiosyncratic nature of research on tools for supporting creativity.

Seven Issues

Three Roles of Tools Supporting Creativity

The workshop participants had lively discussions on the roles of tools for supporting creativity. Such tools may be positioned in terms of three dimensions, analogous in sports to dumbbells, running shoes, and skis.

The first dimension includes tools to train people to develop creativity, or skills of creative thinking (for instance, see tools by Resnick et al. and Eisenberg et al. in Section xxx-CompositionTool). Such tools aim at helping people to develop skills to engage in creative ways of looking at problems and framing solutions by using these tools, and to maintain such skills even without using the tools. In this sense, tools in this dimension are like dumbbells used to develop muscles — once developed, muscle can be used for other kinds of physical exercise than merely using dumbbells. The second dimension includes tools to support people's creative process while engaging in a creation task (for instance, tools by Myers and Pausch in Section xxx-CompositionTool, Terry et al. [2002][2004] and Nakakoji & Yamamoto [2005]). These tools are like high-tech running shoes, with which runners, especially skilled ones, can run faster and/or more comfortably. People can still run without wearing such shoes, but they would have different kinds of running experiences, and probably better ones, by wearing the shoes. The third dimension includes tools to enable people to have new kinds of experiences that they would not be able to have without using these tools (for instance, see interactive media art systems, such as those described by Edmonds & Candy [2002] and Giaccardi [2005], as described in Section xxx-MediaArt), allow people to engage in completely new experiences of producing expressions. For our analogy, the act of skiing cannot take place without wearing skis.

These three dimensions are by no means exclusive. Each tool, described within the research framework of supporting creativity, simultaneously embodies multiple aspects. Yet, it is important to be aware of the differences among them. The workshop has seen the beginning of a taxonomy emerging, and we need to further develop it to more adequately refer to each aspect of the research field.

Engagement, Embodiment, Trust, and More

In the field of human-computer interaction (HCI) research, usability and learnability have been studied regarding the quality of computational tools. Those concepts have been primarily measured in terms of efficiency and productivity.

Designing tools for supporting creativity (in all of the three aspects described above), in contrast, needs to take into account new concepts that have not been considered within the traditional HCI framework. Studies suggest that supporting creativity requires people to experience a "flow" [Csiksentmihalyi 1990],

which needs tools *engaging*. The relationship between users and a tool might be better described as *embodiment* rather than *use* [Fels 2004]. Information provided by tools needs to be *trustful* for people to use it as a source for nurturing creativity [Nakakoji, et al. 2000]. Logical *aesthetics* of systems [Hallnaes, Redstroem 2002] play an important role for people to regard tools as expressive media. The utility of such tools may be described in terms not necessarily of objective measurements, such as productivity and efficiency, but of subjective ones, such as *values* [Gaver et al. 2004].

Creative Processes in Software Development

Software development, especially programming, was referred to a number of times during the workshop as a representative design practice in a knowledge-intensive domain. However, many participants were also aware of the existence of counter arguments, such as "*programming is boring*."

In fact, although the software engineering community has changed its focus not only on organizations but also on individuals (such as with Personal Software Processes [Humphrey 1997]), the predominant view still holds that there should be no fundamental differences among individual programming processes. The psychology of programming has primarily looked at the differences of programming productivity and efficiency between experts and novices, and studied the benefits of programming features (e.g. IF statement design), methods (e.g. object oriented), and usage (e.g. mnemonic variable names)[Shneiderman 1980][Soloway 1984], but not so much on individual differences in programming processes.

Having seen the emergence of the eXtreme Programming (XP) style [Beck 1999] being accepted within the industry, especially the successfully deployed pair-programming style, researchers in the software engineering community have started to seek scientific accounts for why such free-form working styles outperform more rigid, structured, process-oriented styles. This trend has made the focus slowly shift more to the human side of programmers, and to programmers' creative thinking processes. It should also be noted that studies have been reported on how open-source software developers work collectively, which demonstrates the aspect of social creativity [Ye et al. 2004].

The workshop participants believed that there is a research opportunity in studying the usability and design of programming languages, notations, and CASE (Computer-Aided Software Engineering) tools (such as Cognitive Dimensions by Green [2000]) by looking at programming as a creative endeavor. We need to study and identify elements of creative programs, strategies, and individuals to support more effective software development.

Cabinets of Curiosity

The first phase of the four-phased creativity model is *collection*. People have historically developed the idea of "cabinets of curiosity," which display things that look curious. Such cabinets seem to help people in the collection phase leading to creative thinking and creative artifacts. Architectural designers as well as industrial designers put large numbers of sketched sheets of papers on walls surrounding their desks, collect magazine clips in albums, and carry their sketch books all the time. These practices also imply that people need to collect "stuff" and be surrounded by it to help them engage in creative practice.

Despite the existence of these practices, however, we still do not have empirical evidence of how they work, and we still do not know what the computational tools deliberately designed to support such a collection process would be. Browsing the Web would certainly serve the purpose, but would it be sufficient? Would carrying their working environment on a laptop PC help? What else could we design for tools to support the collection process?

Learning from Media Arts

Creativity is often associated with art, and research on tools for supporting creativity is often naively viewed as supporting artists. None of the workshop participants, however, believed that we could develop tools supporting creativity of artists if we take a romantic account of design by which a creative process is

viewed as a result of “magical abilities of creation” by “imaginative masterminds” [Fallman 2003]. Rather, our target users have been, and will be, design practitioners and children, taking a pragmatic account of design [Fallman 2003] by which a creative process is viewed as a reflective practice [Schoen 1983].

Arts, especially media arts in this context, become relevant to the workshop by looking at media arts as tools for supporting creativity (as more thoroughly elaborated in Section xxx-MediaArt). As stated above, concepts that have not been well understood, such as engaging, embodiment, aesthetics, or trust, need to be taken into account in designing and evaluating tools for supporting creativity. As researchers, our goal is to develop rigorous accounts and identify scientific evidence for how such concepts are instantiated within tools.

Although we do not yet know how to do it, some media art works achieve some of the concepts, such as engaging experience for participants (see Section xxx-MediaArt for further explanation). Our research could then treat them as success cases and draw scientific accounts for which aspects of the works achieve what concepts, by deconstructing them and re-appropriating them. This type of deductive reasoning could be one way to address the challenges of research on tools to support creativity.

Creativity in Context

Many of the workshop participants take the view that creative practice is a never-ending endeavor. Producing an artifact should not be regarded as a one-shot affair, but rather as formulating a growing experience engaging in the development of creating generations of artifacts.

In this regard, a statement of “tools supporting creativity” might have to be restated as “tools supporting creativity in what context.” This aspect was brought up when Gary Olson reported the result of a study, saying that the sum of the outcomes of individuals’ brain storming sessions outperforms the outcome of a group brain storming session in terms of quality and speed. Yet, the real value of group brainstorming seems to be not within the quality of the brainstorming per se but within information sharing and value sharing. The subsequent processes would work better having such shared experience during a group discussion.

Tools for supporting creativity could also face the same challenge. Some tools work well for a user to produce a creative artifact at a certain stage. However, if the user needs to keep working on the artifact in subsequent stages, different tools might work better as a whole. In modeling, designing, and evaluating tools for supporting creativity, therefore, we need to identify what contexts of the creativity our tools are aiming at. Otherwise we could easily fall into a fruitless discussion by referring to creativity in different contexts.

Beyond Adaptation and Beyond End-User Modifiability

As discussed above, aspects conventionally associated with the quality of tools do not necessarily hold for tools supporting creativity. If the quality of creativity support tools could be measured only in terms of subjective factors such as values, then since different individuals have different value systems, there may be creativity support tools not for all of us but only for a subset of people who share the same value systems. For instance, when designing creativity support tools for programmers, the ease of use might not necessarily be a requirement for professional programmers; skilled professional programmers often find pride in their being able to use complex notations within difficult-to-learn environments, and some may not like to use too-easy-to-learn tools that may threaten their professional identity.

This seems to suggest almost a paradigm change for existing HCI research, which has been seeking “appropriate” models and tools for certain domains. Adaptive mechanisms and end-user modifiability have been explored as ways to allow people to adjust tools for individual differences, but such minor adjustments cannot afford the variety of tool needs. End-users cannot modify a Porsche to turn it into a Mercedes; they are two fundamentally different tools, both of which are for those who are fond of high-quality driving experiences, but each designed with a completely different philosophy than the other.

Concluding Remark

Because creativity is such a humane matter, designing, developing, and evaluating tools for supporting creativity will uncover issues and challenges that have not been so obvious in the traditional HCI research framework. Research on tools for supporting creativity would make computer technologies truly human-centered.

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Creativity and Distributed Intelligence

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Distributed Intelligence

There is overwhelming evidence that research on creativity should be grounded in the basic assumption that power of the unaided individual mind is highly overrated. [John-Steiner, 2000]. Although creative individuals are often thought of as working in isolation, much of our intelligence and creativity results from interaction and collaboration with other individuals, with their tools and with their artifacts [Csikszentmihalyi, 1996]. In many traditional approaches, *human cognition* has been seen as existing solely "inside" a person's head, and studies on cognition have often disregarded the physical and social surroundings in which cognition takes place. *Distributed intelligence* [Fischer, 2005; Hollan et al., 2001; Salomon, 1993] provides an effective theoretical framework for understanding what humans can achieve and how artifacts, tools, and socio-technical environments can be designed and evaluated to empower human beings and to change tasks.

Individual and Social Creativity

Individual Creativity. The claim by Csikszentmihályi [Csikszentmihalyi, 1996] that *"an idea or product that deserves the label 'creative' arises from the synergy of many sources and not only from the mind of a single person"*, does not exclude individual creativity. Creative individuals can make a difference, as analyzed and shown by Gardner [Gardner, 1995] in exemplary cases, such as movie directors, champions of sports teams, and leading scientists and politicians. Individual creativity comes from the unique perspective that the individual brings to bear in the current problem or situation. It is the result of the life experience, culture, education, and background knowledge that the individual has, as well as the personal meaningfulness that the individual finds in the current situation. Creative actions cannot be completely planned actions; rather, they can only be situated actions, after reflecting upon the situational talk-back of the environments, either technical or social [Schön, 1983]. Therefore, individual creativity can be greatly enhanced by providing appropriate socio-technical environments [Mumford, 1987]. Creativity flourishes best in a unique kind of social environment: one that is stable enough to allow continuity of effort, yet diverse and broad-minded enough to nourish creativity in all its subversive forms.

Social Creativity. Much human creativity arises from activities that take place in a social context in which interactions with other people and the shared artifacts are important contributors to the process. Social creativity comes alive in socio-technical environments in which communities collaborate.

Communities can be characterized by distances and diversity and by the resulting *division of labor* [Levy & Murnane, 2004], among individuals who have unique experiences, varying interests, and different perspectives about problems, and who use different knowledge systems in their work. Shared understanding that supports collaborative learning and working requires the active construction of a knowledge system in which the meanings of concepts and objects can be debated and resolved. In heterogeneous design communities, such as those that form around large and complex design problems, the construction of shared understanding requires the interaction and synthesis of several separate knowledge systems.

Distances and diversity should not be considered as constraints to deal with but as opportunity to generate new ideas, new insights, and new environments [National-Research-Council, 2003]. The challenge is often not to reduce heterogeneity and specialization, but to support it, manage it, and integrate it by finding ways to build bridges between local knowledge sources and by exploiting conceptual collisions and breakdowns as sources for innovation. Social creativity can be distributed (1) *spatially* (across physical distance), (2) *temporally* (across time), and (3) *conceptually* (across different communities), and

(4) *technologically* (between persons and artifacts) [Fischer, 2005]. This distributed fabric of interactions can be supported by integrating diversity, making all voices heard, increasing the back-talk of the situation, and providing systems that are open and transparent, so that people can be aware of and access each other's work, relate it to their own work, transcend the information given, and contribute the results back to the community (as illustrated by the "collect / relate / create / donate" model [Shneiderman, 2002]).

Integrating Individual and Social Creativity. Creativity research should be grounded in the basic assumption that there is an *"and"* and not a *"versus"* relationship between individual and social creativity. Individual and social creativity can be integrated by means of proper collaboration models, appropriate community structures, boundary objects, process models in support of natural evolution of artifacts, and meta-design [Fischer et al., 2005]. By integrating individual and social creativity, support can be provided not only for reflective practitioners but also for *reflective communities*.

Towards a Enriched Framework for Creativity

To design the creativity support tools of the future requires an enriched framework for creativity. The following paragraphs describe some specific dimensions of such a framework (obviously many more dimensions exist and need to be developed and articulated).

Externalizations are critically more important for social interactions because groups have "no head". *Externalizations* support creativity based on: (1) they produce a record of our mental efforts that is outside us rather than vaguely in memory; (2) they cause us to move from vague mental conceptualizations of an idea to a more concrete representation of it, creating situational back-talk and making thoughts and intentions more accessible to reflection; (3) they provide a means for others to interact with, react to, negotiate around, and build upon an idea; and they contribute to a common language of understanding.

Meta-Design. To bring social creativity alive, media and environments must support meta-design. M*eta-design* [Fischer et al., 2004] characterizes objectives, techniques, and processes to allow users to act as designers and be creative. The need for meta-design is founded on the observation that creativity requires open systems that users can modify and evolve. Because problems cannot be completely anticipated at design time when a system is developed, users at use time will discover mismatches between their problems and the support that a system provides. These mismatches (perceived as breakdowns and conceptual collisions) serve as potential sources for new insights, new knowledge, and new understanding. Meta-design advocates a shift in focus from finished products or complete solutions to conditions, contexts, and tools for users that allow them to be creative in further evolving artifacts and organizations [Hippel, 2005].

Meta-design supports *informed participation* in which participants from all walks of life (not just skilled computer professionals) transcend beyond the information given to incrementally acquire ownership in problems and to contribute actively to their solutions. It addresses the challenges associated with open-ended and multidisciplinary problems. Meta-design requires *active contributors* (people acting as designers in personally meaningful activities), not just consumers [Fischer, 2002]. Creativity needs the "synergy of many", and this kind of synergy is facilitated by meta-design. However, a tension exists between creativity and organization. A defining characteristic of social creativity is that it transcends individual creativity and thus requires some form of organization; but elements of organization can and frequently do stifle creativity [Florida, 2002].

From Reflective Practitioners to Reflective Communities. The objective to educate "Renaissance scholars" (such as Leonardo da Vinci, who was equally adept in the arts and the sciences [Shneiderman, 2002]) is not reasonable in today's world [National-Research-Council, 2003]. We need to invent alternative social organizations that will support *"collective comprehensiveness through overlapping patterns of unique narrowness*" [Campbell, 2005] by integrating different interdisciplinary specialties which are partially overlapping with each other. Such an architecture will provide a foundation that people can understand each other based on common ground but at the same time their expertise will be complementary because they will know different things. This architecture will allow us to move beyond

the isolated image of the reflective practitioner towards the sustainability and development of *reflective communities*.

From Given Tasks to Personally Meaningful Activities. To motivate people to become active contributors and designers and share their knowledge requires a new "design culture", involving a *mindset* change [Fischer, 2002] and principles of *social capital* accumulation [Florida, 2002]. But before new social mindsets and expectations can emerge, users' active participation must be a function of simple motivational mechanisms and activities considered *personally meaningful*. Sustaining personally meaningful activities is essential for creativity. People are willing to spend considerable effort on things that are important to them. The value dimension for truly personal meaningful activities is more important than the effort dimension.

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Challenges for Future Research Activities and Projects focused on "Software Tools and Socio-Technical Environments to Enhance Creativity"

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The goal of this summary statement is to provide initial objectives for stimulating scientific research and education projects focused on *creativity*. The challenge for the educated knowledge workers of the future is *"not to work harder, but to work smarter"*. As intellectual work based on routine cognitive skills is distributed and outsourced around the world, the challenge will be to raise the level of creativity contributions.

The challenges for future research activities and projects focused on "Software Tools and Socio-Technical Environments to Enhance Creativity" include:

- evolving existing and developing new theories of creativity (incorporating social, technical, and organizational dimensions) grounded in a deep understanding of *creativity;*
- identifying the fundamental role of creativity in *all* disciplines (science, design, engineering, art, business, education..);
- radically new *creativity support tools* that facilitate and enhance the development of creative thinking and creative expression grounded in the ongoing technology changes that will impact creativity;
- exploration and impact of these new creativity support tools in a broad spectrum of intellectual activities, including: problem framing and problem solving, decision making, collaboration, composition, visualization;
- design of *processes* supporting creativity (based on what enhances or hinders creativity) including: the development of organized approaches to creativity that are grounded in the multi-dimensional character of creativity; the importance of end-user development for creativity; the impact of creativity on *new divisions of labor*;
- design of *socio-technical environments* to support and enhance creativity;
- *systematic foundations* for the design, assessment, and wide-spread distribution of creativity support tools;
- development of *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;
- exploration and use of assessment and evaluation frameworks from different disciplines including: formal user studies, ethnographic studies analysis of social impact, cultural meaning;
- frameworks to *educate the creative minds of the future* by integrating knowledge about creativity into educational curriculum and professional training;
- new *inter- and transdisciplinary collaborations* focused on creativity including social and technological infrastructures to identify common ground and to create a shared understanding;
- understanding the role of *diversity* and *distances* (spatial, temporal, conceptual, technological) in creativity;
- studies of *creative people* and *creative artifacts*;
- creating repositories of *creative artifacts to be studied* and *further evolved;*

- understanding the importance of creativity in knowledge work, lifelong learning, and integration of working and learning.

Exemplary Research Activities

The following are illustrations of research activities that might be incorporated into a project:

- **Empirical studies of creativity, creative people, and creative artifacts**
  - study of exemplary successes and best practices;
  - novel methodologies for empirical design research;
  - understanding the relationship between individual and social creativity.
- **Integrating research and education**
  - development and documentation of knowledge relevant to all aspects of creativity, e.g., principles, experiences, guidance, and problem-solving processes;
  - a strong emphasis on education and learning by exploring questions such as: how can we help people (across their whole lives) learn to think and act more creatively? How can we help people develop the "habits of mind" or "dispositions" (e.g., willingness to take risks, persevere when things go wrong) that are key to creativity?
  - formulation of teachable creativity knowledge, experiences, and best practices
- **Creativity enhancing socio-technical environments for specific communities**
  - creation and study of design environments supporting specific communities;
  - creation and study of design environments supporting inter- and transdisciplinary communities.
- **Centers of Excellence for Creativity Research, Practice, and Education**
  - exploring and creating the necessary conditions for such centers in the 21st century;
  - creation of test beds for creativity research