Creativity Support Tools: Accelerating Discovery and Innovation

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How can designers of programming interfaces, interactive tools, and rich social environments enable more people to be more creative more often?

Introduction

Since scientific discoveries and engineering innovation bring broad benefits, improved tools that advance individual, group and social creativity are important contributions. The current and forthcoming generations of programming, simulation, information visualization, and other tools are empowering engineers and scientists just as animation and music composition tools have invigorated filmmakers and musicians (see sidebar by Linda Candy). These and many other creativity support tools enable discovery and innovation on a broader scale than ever before; eager novices are performing like seasoned masters and the grandmasters are producing startling results. The accelerating pace of academic research, engineering innovation, and consumer product design is amply documented in journal publications, patents, and customer purchases.

While telescopes and microscopes extended an individual's perceptual abilities to make discoveries, modern creativity support tools also enable new forms of expression for individuals, and they are especially potent in supporting group collaboration and social creativity (Table 1). Creativity includes discovery or invention of a significant idea, pattern, method, or device that gains recognition from accepted leaders in a field, while innovation requires further steps to ensure adoption (see section on *Defining and supporting creative processes*). For example, many researchers extend their perceptual abilities by applying general purpose scientific or information visualization tools, which enable them to make discoveries about their data (Figure 1). Other domain experts, such as genomic researchers, use specialized visual analysis tools to discover biological pathways. Scientists and engineers draw on powerful mathematical, design, and simulation tools to support their discovery and innovation (Figure 2). New media artists realize their desire for personal expression with powerful development environments that support animation, music, or video editing tools.

Even more remarkable opportunities have emerged for group collaboration across time and space, as afforded by programming environments that enable distributed teams to accelerate development of software projects. Still broader impacts stem from social creativity tools, such as wikis, citizen journalism, and media sharing, that enable thousands of cooperating individuals to create and share significant new content and services.

Never before has it been possible to arrange rapid and broad collaboration among numerous content creators and service providers. Understanding the passion and persistence required for individual creativity is difficult enough, so designing for social creativity requires rigorous research, with fresh theories of collective efficacy and the motivational impact of rewards and recognition (see sidebar by Gerhard Fischer and Elisa Giaccardi).

An historic shift

During the past half century computing professionals have developed potent productivity support tools that reduced manufacturing costs, tightened supply chains, and strengthened financial management. These business productivity support tools were designed to meet clear requirements such as speeding insurance claims, reducing costs for airline reservations, or simplifying order entry. These tools were conveniently evaluated by standard measures such as time per task, cost per transaction, and errors per order.

But now, a growing community of innovative tool designers and user interface visionaries are taking on a greater challenge. They are moving from the safe territory of productivity support tools to the risky frontiers of creativity support tools. The challenges they face stem from the vague requirements for discovery and innovation, as well as from the unorthodox user behaviors and unclear measures of success. The risks are high, but so are the payoffs for innovative developers, ambitious product managers, and bold researchers. Creativity support tools extend users' capability to make discoveries or inventions from early stages of gathering information, hypothesis generation, and initial production, through the later stages of refinement, validation, and dissemination.

A way forward for research and development on creativity support tools has been to focus on specific tasks that support discovery in the sciences, exploration in design, innovation in engineering, and imagination in the arts. For example, we already know that an accelerator for creative efforts is the capacity to locate, study, review, and revise existing projects and performances, such as open source software modules, Web page source code, architectural drawings, or music scores. The Web has done much to make existing projects and performances accessible and search engines like Google have helped innovators to find what they want. Future search engines can be designed far more elegantly to enable users to find the relevant results with specific features. While current search engines can find sonatas, singling out those in a romantic style with accelerating tempo written in France during the 20th century may be harder to find. Often searchers need help in discovering the range of possibilities, while learning the concepts and terminology. Such exploratory searches may take users weeks or months to complete, requiring note taking, consulting with colleagues and refining their goals. Of course, intellectual property policies must be modernized, to let users more easily build on previous work while paying fair licensing fees. Diverse proposals for copyright reform, patent modernization and the Creative Commons offer modernizations of legal structures that accommodate these new technologies and new ways of working.

A second example of creativity support is the capacity for users to rapidly generate multiple alternatives, explore their implications, or revert to earlier stages when needed. Hypothesis generation for scientists, prototypes for software engineers, models for architects, and sketches for artists are well established as important steps in their agile creative processes. Certainly well designed software tools can help creators in generating multiple possibilities, showing the implications of their choices and tracking their design decisions (Terry & Mynatt, 2004). The best tools enable users to save their history, edit it, email it, and replay it thousands of times with different parameters.

These and other examples distill emerging design principles, but skeptical business professionals, inspired artists, and diligent academics still worry about whether creativity support is an achievable goal. They may deride suggestions that creative human endeavors can be aided by inherently structured user interfaces that inevitably limit exploration. These concerns are taken seriously by creativity support tool designers, who recognize the difficulties, but already see grand successes and future opportunities. Just as telescopes, microscopes, and cameras are powerful devices that enable discoveries and innovations, they are still only tools; the act of creation is carried out by the users.

As a computer and information science research topic, creativity is still emerging. The ACM Computing Reviews Classification has more than 1500 entries, but does not include creativity, discovery, exploration, or innovation. By contrast, creativity-related topics are currently high in national priorities worldwide, generating calls for support from national science research boards (NSF, 2006; NAS 2003). At the same time, national legislators and regional planners are concerned about promoting competitiveness, enhancing workplace innovation, and attracting creative industries. Their emphasis ranges from support for game design entrepreneurs and film animation companies to pharmaceutical drug discovery teams and consumer product designers.

Traditional descriptions of creativity often suggested that creative personalities -- the Einsteins and Picassos of the world -- were rare occurrences with special talents who came along once in a generation to transform the world. The modern belief, held by many teachers and researchers, is that creativity can be taught, and that everyone can be creative. This is a remarkable transformation from 400 years ago, when scholars devoted much energy to copying or translating the words of Aristotle and other long-dead authors. While learning from and building on past work is important, the World Wide Web and the broad use of information and communications technologies has raised expectations that every student should write poems/programs, make photos/videos, design interfaces/games, and then disseminate them to others. The widespread availability of books and then electronic media transformed education so that now every student is expected to compose original texts, videos, animations, music, and art. Teachers also expect their students to produce science and engineering projects with fresh empirical evidence, original discoveries, or innovative devices (Shneiderman, 2002).

Defining and supporting creative processes

While there has been extensive research on creativity in many disciplines, the topic is a relatively new one in computer and information science. The excellent *Handbook of Creativity* [Sternberg, 1999] covers many research directions but terms like 'computer' and 'user interface' don't even make it into the index. The large literature on creativity, discovery, design, innovation, and composition may be sorted into three schools:

1) *Structuralists:* believe that people can be creative if they follow an orderly method, typically described with several stages, such as preparation, incubation, illumination, and verification. There is ample anecdotal evidence that great breakthroughs happened according to this generic method, but many variations are promoted by self-help books, organizational creativity consultants, and systematic discovery methods such as TRIZ (Theory of Inventive Problem Solving, http://www.triz.org). Systematic approaches to exploratory search include the Arrowsmith (http://arrowsmith.psych.uic.edu) method for finding unusual overlaps in distant disciplines and the combinatorial hypothesis generation (exhaustive search) for multiparameter simulations.

2) *Inspirationalists:* argue that breaking away from familiar structures elicits creative solutions. They advocate working on unrelated problems, getting away to scenic locations, and viewing random photos or inkblots. Inspirationalists promote meditation, hypnosis, dreaming, and playful exploration. They seek to liberate thinking from old habits so as to break through to the Aha! moment of inspiration. This school of thinking advocates sketching to quickly explore possibilities, concept mapping to discover unexpected relationships, and visualization strategies to see the big picture.

3) *Situationalists:* recognize that creative work is social. They seek to understand the motivation of creative people, their family history, and their personal relationships with challenging teachers, empathic peers or helpful mentors. They understand the need for distinctive forms of consultation at early stages when fear of rejection, ridicule, and rip-off are high versus later stages when validation, refinement, and dissemination are prominent. Situationalists seek to understand the motivating roles of rewards and recognition (does the Nobel Prize promote creative work?), as well as competition vs. collaboration.

Each of these three schools offers important lessons for designers of creativity support tools. Structuralist thinking encourages systematic tools that include progress indicators with reminders of what is still needed. The inspirationalist view supports development of image libraries, thesauri, sketching interfaces, and concept mapping tools. Situationalists broaden the designers's view to include email and collaboration tools, as well as the e-science notebooks that guide users and coordinate groups through scientific processes over weeks, months, and years.

A prominent situationalist researcher is Mihaly Csikszentmihali, whose in-depth interviews with 91 famously creative people [1996] led him to make these useful, but provocative definitions:

1) Domain: "consists of a set of symbols, rules and procedures" that are accepted and used by a well-defined community, e.g. mathematics or biology

2) Field: the respected leaders in a domain: "the individuals who act as gatekeepers to the domain...decide whether a new idea, performance, or product should be included"

3) Individual: creativity starts with individual motivations and insights, but requires social confirmation. He defines creativity as "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"

On first reading, Csikszentmihali's definition may be disturbing, since it implies that contributions are creative only when recognized by journal editors, patent examiners, symphony directors, etc. Many people feel they are able to judge their own contributions, but Csikszentmihali's definition asserts that to gain recognition, contributions must be judged by accepted leaders in a field. He makes clear that creative people need to respect previous work and to present discoveries and innovations in a way that clarifies their contributions. Csikszentmihali's definition stresses context, making creativity a social and political process in which the structured methods and Aha! moments are merely middle stages.

Changing mindsets

Getting information technology companies and academic researchers to invest resources in creativity-related research and development requires at least three significant changes in mindsets.

1) *developers* who understand that benchmark task completion is giving way to playful exploration, richer search features, generation of multiple alternatives, and easy backtrack with rich history keeping. They also recognize that web-enabled social creativity environments can support innovative approaches to software development, content creation, and rapid dissemination of new ideas.

2) *product managers* who conceive of their customers as creators, rather than merely users or consumers, are already changing their requirements analysis, feature selections, and marketing strategies. They know that creative people want open systems which they can extend and that they want an audience, feedback, rewards, and recognition.

3) *researchers* who study and evaluate software usage are getting past old strategies of controlled studies and short-term usability testing to embrace ethnographic styles of observation, long-term case studies, and data logging to understand patterns of usage. They know that motivation, empathy, playfulness, and surprise are part of the creative landscape. They also know that getting the right mix of individual discovery, supportive consultation, and community brainstorming generates high user engagement.

These changes to expectations for individuals and their institutions are important first steps in enabling more people to be more creative more often. But even with clarity about the goals, there are still numerous challenges such as developing design guidelines and appropriate research methods.

Design principles for creativity support tools

World-famous architects such as Norman Foster and Frank Gehry claim that their innovative buildings would not be possible without computer tools that enabled them to create their complex structures. Excellent interfaces, sometimes with rich domain-specific features, are essential for creativity support, as users need to apply their cognitive resources and passions fully to their discoveries and innovations. While experience across domains is diverse, there are underlying principles to guide designers (Myers et al., 2000 ; Shneiderman et al., 2006). These principles include :

Support exploratory search: to be successful at discovery and innovation users should be aware of previous and related work, but finding relevant items may prove challenging with traditional keyword search. Google is great for fact finding, and it can be helpful for exploratory search projects, but there is much room for improvement. The inspirationalist school of creativity encourages viewing many relevant exemples of previous work to engage innovators in a creative mind set. Faceted search (simultaneous menus on independent aspects such as people, geography, and time) helps guide users by providing compact visual cues about attributes and attributes values. Dynamic queries (changes to sliders, selectors, and filters, producing rapid changes to displays) support rapid incremental and reversible exploration that enables users to learn about distributions, gaps, and outliers. Improved search services provide rich mechanisms for organizing search results by ranking, clustering, and partitioning with ample tools for annotation, tagging, and marking. Advanced search services also enable seamless collaboration with shared views, chat rooms, and emailing of result sets. Since serious discovery and innovation may require group processes that last for weeks or months, as in legal, patent, or scientific article searches, history keeping facilities are helpful, as are overviews of what has been done and what still needs doing.

Enable collaboration: While the Aha! moments of discovery and innovation are very personal, the processes that lead to them are often highly collaborative. Inspirationalists and situationalists claim that collaborations at early stages revolve around problem definition and setting goals, so consultations must be handled carefully because innovators fear rejection, ridicule, and rip-off. Communications systems that let users expose their uncertainties in a safe environment could help build trust, and designs that record who said what can document contributions to emerging ideas. Trust, accurate records, and safe exchanges are also needed in the middle stages when information gathering, idea refinement, and knowledgeable partners are important. In later stages, when validation and dissemination become dominant, finding appropriate test situations, preview audiences, and media partners is helpful. These processes are well understood for individuals and small groups, but technology support for them is marginal. For the larger communities engaged in social creativity, wholly new forms of collaboration are emerging. Wikipedia and its support environment, Wikimedia, have proven to be remarkable and surprising success stories, defying expectations by finding a good balance between free-wheeling individual effort and well-enforced administrative principles. Each individual contribution to Wikipedia may be small, but the Wikimedia environment produces an intense collaborative effort that leads to an impressive and original product. Thomas Edison quipped that innovation was 1% illumination and 99% perspiration, but now he might remark that innovation is 1% inspiration and 99% collaboration.

Provide rich history keeping: Many people believe that discovery and innovation processes take many forms, so it is hard to provide precise guidance in a step-by-step manner. But after casting aside rigid and doctrinaire strategies, semi-structured methods or at least an orderly process has repeatedly been shown to be beneficial. The structuralist school embraces systematic approaches; sometimes around the traditional phases of preparation, incubation, illumination, and verification, but often around more carefully defined methods such as the forty potential phases of TRIZ. While Thomas Edison tested more than 4000 filament variations for his light bulb, newer forms of structured discovery apply computer-based exhaustive search of millions of cases to understand optimal conditions and relationships among parameters. Whether discoverers and innovators used structured or free-form thinking, the benefits of rich history-keeping are apparent. Users have a record of which alternatives they have tried, they can compare the many alternatives, and they can go back to earlier alternatives to make modifications. History-keeping on computers has still more benefits, such as sending interesting cases to colleagues for comments and creating macro processes that can be run repeatedly on new data.

Design with low thresholds, high ceilings, and wide walls: This metaphoric description of desirable attributes for creativity support tools suggests that tools should be easy for novices to get started with, yet provide ambitious functionality that experts need. Good tools should also have a wide range of functionality so that many different services are provided, from data input and statistical analyses to report generation. A single tool with a uniform user interface reduces frustrating file conversions and enables users to concentrate on their problems. Of course, there are limits to what one tool can do and also good arguments for modular designs, as well as domain-specific variations. Still, when users can import datasets easily, handle missing data, transform values, try multiple visualizations, run statistical tests, include annotations, and export subsets of data in desired formats, then they are free to concentrate on their exploration rather than cleaning data, recording comments, and transforming file formats. One strategy for satisfying this principle is to use a multi-layer interface design that lets novices begin a layer 1 and move up as their experience allows and needs demand. Many video games have dozens of layers, most search engines have novice and advanced layers (Google, Yahoo), many art and video tools have three or more workspaces (Apple Final Cut Pro, Adobe Premiere), and some tools have as many as eight layers to accommodate a wide range of expertise and ambition.

Rigorous Research Methods

These design principles for creativity support tools and the tools themselves would be difficult to validate with controlled studies that measured time to correct completion of benchmark tasks. Three hundred years of scientific methods based on a reductionist model and controlled experimental studies have produced huge benefits, but the complex nature of human discovery and innovation cannot be studied like pendulums or solid state materials (Basili et al., 1999; Fjermestad & Hiltz, 2000).

Researchers are beginning to understand that design of discovery and innovation tools is a worthy subject of study, but they are often torn by devotion to traditional controlled studies. They also face pressure from many journal and conference reviewers, who favor statistically-significant results, even when laboratory controlled studies with many participants are inappropriate. The intense desire for close study of domain experts as they make discoveries has led many researchers to adopt case study, observational, and interview methods with small numbers of users over weeks and months. Their goal is to capture the processes that precede breakthrough incidents and to collect evidence that supports hypotheses about how software design features promote creative moments.

The intense desire for validity that comes from close observations has led many researchers to take fresh approaches to other research goals like replicability and generalizability. Until many more case studies are collected and many related problems are studied, carefully documented methods are needed to answer critics who are legitimately concerned about misleading interpretations based on experimenter bias (Hewett, 2005). Individual case studies are meant to provoke multiple case studies that replicate findings with diverse users and problems. As multiple case studies replicate results, researchers gain confidence in the replicability and generalizability of cause and effect conjectures. Many researchers have already demonstrated high payoffs in understanding how powerful tools can support creative people. These researchers also argue that creative work in science, design, or the arts evolves so rapidly that replicability has a different meaning than in physical sciences research where the properties of electrons or tensile strength of steel can be studied again and again under diverse conditions. In medicine, business, and other research domains, when case study methods are based on established procedures to limit bias, they are accepted as valuable contributions.

Year-long studies of artist-technologist collaborations (see sidebar by Linda Candy) and a long tradition of ethnographic research have influenced the multi-dimensional in-depth long-term case studies, which are emerging as an accepted research method for scientific discovery and design innovation (Shneiderman & Plaisant, 2006). The key idea is to closely study domain experts who are working on their own problems over a period of weeks or months. This is a form of qualitative hypothesis testing, in which the goal is to collect evidence about how a creativity support tool benefits its users. When the focus is on documenting and understanding how specific features contribute to successful outcomes, the researchers often produce insights that have substantial and broad value.

Researchers become more than participant observers, as they may help the users to apply the tool effectively while recording their reactions. In a growing number of studies, once a week visits for 1-2 hours over a 1-4 month period enabled participant observers to gather evidence about what worked and what did not. The users benefit by having access to novel technologies and the participation of sympathetic researchers, who are eager to see the users succeed. Careful logs of tool usage and audio or video recordings document critical incidents and reveal problems with the tool design or usage. The close linkage of researchers and users violates traditional experimental design principles, but it seems necessary to understand creative processes that involve individual, group, and social environments. Complementary analyses from usage logs, interviews, surveys, or focus groups, usually called triangulation, can contribute additional insights and increase perceived validity.

Conclusion

Creativity support tools have been around for as long as people have been creative. However, designers of modern computer-based environments are enabling new discovery and innovation processes for individuals, groups, and communities. In order to improve their design, they need refined theories and rigorous empirical studies based on new research methods. The close collaboration required by multi-dimensional in-depth long-term case studies can produce breakthrough insights about how discovery and innovation happen.

The growth of interest in creativity support tools in recent years is gratifying. The June 2005 U. S. National Science Foundation (NSF, http://www.cs.umd.edu/hcil/CST) sponsored workshop on the topic (Shneiderman et al., 2006) inspired research under the CreativeIT program, a strong commitment to discovery and innovation research in the NSF five-year strategic plan (Sept 2006), and the ambitious billion dollar vision for cyber-enabled discovery and innovation research. The risks are high and the scientific methods novel, but the payoffs are substantial in bringing about thrilling moments of scientific discovery and engineering innovation.

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Individual & Group Creativity Support Tools	
Information visualization tools	Spotfire, SAS JMP, DataDesk, ManyEyes, Digg
Specialized visualization tools: GIS	Google Maps, ArcInfo
Specialized visualization tools: gene expression analysis	GeneSpring, DNASTAR
Mathematical manipulation	MatLab, Mathematica
Engineering, architectural, industrial, product design	Autocad Inventor, DataCAD, SolidWorks
Simulation	SPICE, Tierra
New media development environments	Max/MSP, Pd, processing
Animation & interaction	Flash, FLEX, OpenLaszlo
Music	Cinescore, Cakewalk Sonar
Video editing	Premier, Final Cut Pro, Lightworks, iMovie, Windows MovieMaker
Concept mapping	Inspiration, MindMapper, MindManager, Axon
Group & Social Creativity Support Tools	
Software development	Eclipse, JDeveloper, Visual Studio
Wikis	Wikipedia, Wikia
Citizen journalism	Blogger, Ohmynews, Slashdot
Media sharing	flickr, YouTube
Music	Garageband, macjams

Table 1: Samples of classes of creativity support tools and examples of products

Figure 1: The IN Cell Analyzer automated microscope was used to identify proteins influencing the division of human cells. After the images were analyzed, quantitative results were transferred to Spotfire DecisionSite. This screen revealed the previously unknown involvement of the retinol binding protein RBP1 in cell cycle control.(Stubbs S & Thomas N, 2006 Methods in Enzymology; 414:1-21.) Retinol a form of Vitamin A plays a crucial role in vision and during embryonic development (Courtesy of Nick Thomas, GE Healthcare).

Figure 2: Using Autodesk Inventor's Design Accelerators for engineering tasks such as shaft design, gear design, and bearing selection, engineers at Stork Townsend Inc. were able to create a custom gearbox with confidence that the unit would perform to expectations in a harsh environment. Shown here, the Worm Gear Generator is used to create matched sets of paired gears used in this gearbox design. All mating assembly constraints are automatically added, and an additional benefit to users is that this same interface is used for any edits to the gear pairs (Courtesy of Autodesk and Stork Townsend, Inc.)

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