Creating Creativity for Everyone: User Interfaces for Supporting Innovation

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Abstract:
A challenge for human-computer interaction researchers and user interface designers is to construct information technologies that support creativity. This ambitious goal can be attained by building on an adequate understanding of creative processes. This paper offers the four-phase genex framework for generating excellence:

- Collect: learn from previous works stored in digital libraries
- Relate: consult with peers and mentors at early, middle and late stages
- Create: explore, compose, and evaluate possible solutions
- Donate: disseminate the results and contribute to the digital libraries

Within this integrated framework, this paper proposes eight activities that require human-computer interaction research and advanced user interface design. A scenario about an architect illustrates the process of creative work within a genex environment.

1. Introduction

Humans have long relied on information technologies. Ancient traders recorded contracts on clay tablets, religious scribes hand copied illuminated manuscripts on parchments, and Guttenberg applied his printing press to reproducing bibles. Print media led to dramatic changes in society, and then modern broadcast media shook the world further with even more rapid and widespread dissemination. Today, even in remote locales, most people have seen TV and heard radio. The emerging World Wide Web is producing a further societal transformation since it shifts the balance towards an individual's capacity to select information in support of entertainment, decision-making, or knowledge work.

But information preservation and dissemination are only two uses of information technologies. A third expectation is that they support rapid two-way communication among people. The historical trajectory is towards greater speed, lower cost, increased bandwidth, and broader access to the means of communication. Writing letters was a rare process among narrow literate segments of ancient societies, but making phone calls is now widespread, and sending email is likely to become as popular.

A fourth expectation is that information technologies support the creation of knowledge or art. Even into the 20th century, scientists, inventors, novelists, and painters were seen as specially gifted citizens whose rare creative productions were treasured. Photography shook the art world because it enabled a majority to produce elegant artifacts rapidly at low cost. Similarly, information technologies could be harnessed to make creativity in many fields more common.

Information technologies that allow more people to be more creative more of the time will have profound effects on every institution. Education will shift from acquiring facts, studying existing knowledge, or even developing critical thinking, to an emphasis on creating novel artifacts, insights, or performances. Medicine's shift from applying standard treatments to tailoring treatments for each patient, reflects the trend to personalization that is already ascendant in marketing and media. Expectations of teachers, lawyers, and designers are likely to rise as creativity is expected on more occasions from more people.

This paper begins with three perspectives on creativity. Then it reviews and refines the genex framework which is a four-phase integrated framework to support creativity (Shneiderman, 1998c). The main contributions are eight activities characterized by user interfaces that support creativity. This list implies a research agenda for human-computer interaction theoreticians, designers, software engineers, and evaluators.

2. Three Perspectives and Levels of Aspriration

The large literature on creativity offers diverse perspectives (Boden, 1990; Couger, 1996; Cave, 1999). One key aspect of creativity is the scope of the creative process. Some writers, I'll call them *inspirationalists*, emphasize the remarkable "Aha!" moments in which a dramatic breakthrough magically appears. Stories of Archimedes (3rd century B. C.) umping from his bath screaming "Eureka!" as he discovered hydrostatics or Freidrich August Kekule’s (1829-1869) dream-given insight about benzene's ring structure emphasize the intuitive aspects of creativity. Most inspirationalists are also quick to point out that "luck favors the prepared mind," thereby turning to the study of how preparation and incubation lead to moments of illumination. The inspirationalists also recognize that creative work starts with problem formulation and ends with evaluation plus refinement. They acknowledge the balance of one percent inspiration and ninety-nine percent perspiration - a flash of insight followed by much hard work to produce a practical result.

Those who emphasize this inspirational model promote techniques for brainstorming, free association, lateral thinking (DeBono, 1973), nd divergence. They advocate strategies to break an innovator’s existing mind set and somehow perceive the problem with fresh eyes. Since they want innovators to get away from familiar solutions, their recommendations include travel to exotic destinations with towering mountains or peaceful waterfalls. Inspirationalists talk about gifted individuals, but usually stress that creativity-inducing thought processes can be taught.

The playful nature of creativity means that software support for inspirationalists emphasizes free association using textual or graphical prompts to elicit novel ideas. Inspirationalists are often oriented to visual techniques for presenting relationships and for perceiving solutions. They would be sympathetic to information and scientific visualization strategies that helped users understand previous work and explore potential solutions. Many writers and software developers of tools such as IdeaFisher or MindMapper encourage two-dimensional layouts of loosely-connected concept nodes to avoid a linear or hierarchical structure. The casual style and freedom from judgment that is implicit in sketching is encouraged. Inspirationalists would also appreciate templates as starting points for an inspirational leap as long as they are coupled with tool palettes to explore fresh combinations.

A second group of writers on creativity, I'll call them *structuralists*, emphasizes more orderly approaches (Mayer, 1992). They stress the importance of studying previous work and using methodical techniques to explore the possible solutions exhaustively. When a promising solution is found, the innovator evaluates strengths and weaknesses, compares it to existing solutions, and refines the promising solution to make it implementable. Structuralists teach orderly methods of problem solving such as Polya's four steps in *How to Solve It* (1957):

1) Understanding the problem
2) Devising a plan
3) Carrying out the plan
4) Looking back

For structuralists, digital libraries of previous work are important, but the key software support comes in the form of spreadsheets, programmable simulations, and domain-specific scientific /

engineering / analytical / mathematical models. These software tools support "what if" process of trying out assumptions to see their impact on the outcomes. They often show processes with visual animations. Structuralists are also visual thinkers but their preferred tools are for drawing flow charts, decision trees, and structured diagrams. Since they favor methodical techniques they are likely to appreciate software support for step-by-step exploration, with the chance to go back, make changes, and try again.

A third group, the *situationalists*, emphasizes the social and intellectual context as a key part of the creative process. They see creativity as embedded in a community of practice with changing standards, requiring a social process for approval from scientific journal editors, museum curators, or literary prize juries. For example, Csikszentmihalyi (1993) sees three components to creativity:

1) the domain, such as mathematics or biology, "consists of a set of symbols, rules and procedures."

2) the field which "includes all the individuals who act as gatekeepers to the domain. It is their job to decide whether a new idea, performance, or product should be included in the domain."

3) the individual person whose creativity is manifest "when a person using the symbols of a given domain such as music, engineering, business, or mathematics 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."

Situationalists are most likely to talk about the influence of family, teachers, peers, and mentors. They consider the influence of challenges from memorable teachers, the strong desire to create, and the pursuit of recognition. For situationalists, vital user interfaces are those that support access to previous work in the domain, consultation with members of the field, and dissemination of results to interested members of the field.

These three perspectives on creativity - inspirationalism, structuralism, and situationalism - are all useful in shaping user interfaces to support creative work. These perspectives are easily combined. User interface designers can develop tools that stimulate inspiration based on previous work, link to associated ideas, and provide templates for action. Designers can build structured tools for exhaustive exploration, which is already a common strategy in computing. Designers can also facilitate consultation by email and more refined methods, to support the social strategies of the situationalists. Sections 3 and 4 expand these possibilities.

A second key aspect of creativity is the level of aspiration. A restricted definition would focus on great breakthroughs and paradigm-shifting innovations (Kuhn, 1996). Einstein’s relativity theory, Watson & Crick’s discovery of DNA’s double-helix, or Stravinsky’s Rite of Spring are often cited as major creative events. Such a definition confines our discussion to rare revolutionary events and a small number of Nobel Prize candidates. A looser definition would include what Kuhn referred to as normal science, useful evolutionary contributions that refine and apply existing paradigms. Evolutionary acts of creativity include doctors making a diagnosis, lawyer’s preparing a brief, or photo editors producing a magazine story. Their work is important in changing someone's life by medical care, legal practice, or journalist reportage and could be helped by software tools. I am most concerned about evolutionary creativity, but of course, software tools that support evolutionary creativity may also help produce revolutionary breakthroughs. On the other hand, it is possible that software tools that support evolutionary creativity restrict thinking too much and are not useful or even discourage paradigm shifts.

A third, still broader, category of creativity is conceivable - impromptu creativity. Can brilliant conversation, musical improvisation, or creative parenting be considered a part of the creativity spectrum? These more spontaneous activities may be creative in a broad sense, but since they seem harder to support, record, and evaluate, we will leave them out for now.

So the focus of this paper is not on revolutionary or impromptu creativity, but on evolutionary creativity. This still covers a wide range of possibilities. Developing software support tools for evolutionary creativity according to the three perspectives identified in this paper - inspirationalism, structuralism, and situationalism - is a sufficient challenge.

It seems necessary to apologize in advance for the hubris or arrogance of proposing technology to aid human creativity. A critic might scowl that creativity is inherently human and no computer could or should be brought into the process. But technology has always been part of the creative process, whether in Leonardo’s paint and canvas or Pasteur’s microscopes and beakers. Supportive technologies can become the potter’s wheel and mandolin of creativity -- opening new media of expression and enabling compelling performances. Secondly, I seek tools that support human creativity and strongly rebel at the suggestion that machines are or can ever be creative. Computers have no more intelligence or creativity than a wooden pencil. People are creative and they have always used advanced technology to raise their potentials.

My expectations are largely positive, but there are many problems, costs, and dangers in anything as ambitious as a tool and framework to support creativity. An obvious concern is that many people may not want to be more creative. Many cultures encourage respect for the past and discourage disruptive innovations. Promoting widespread creativity raises expectations that may change employment patterns, educational systems, and community norms. Introducing computer supports for creativity may produce greater social inequality as it raises the costs for those who wish to participate. Finally, these tools may be used equally by those who have positive and noble goals as well as by dictators or criminals who seek to dominate, destroy, or plunder.

These fears are appropriate and reasonable cautions must be taken, but support for innovation could lead to more rapid positive changes to our world. Widespread access to genex tools could help with major problems such as environmental destruction, over population, poor medical care, oppression, and illiteracy. It could contribute to improvements in agriculture, transportation, housing, communication, and other noble human endeavors.

3. Genex: a four-phase framework for generating excellence

This paper combines and extends two previous efforts. The genex framework (Shneiderman, 1998c) was a first attempt to build on Csikszentmihalyi’s approach, by supporting access to the domain and consultation with the field. The name genex (generator of excellence) was chosen to echo Vannevar Bush’s memex (memory extender). The genex framework had four phases:

collect, create, consult, and disseminate. This paper refines the genex framework by expanding its scope and being more precise about what user interface tools are needed. The second source for this paper is the educational philosophy, relate-create-donate (Shneiderman 1998b), that emphasized collaborative teams working together to produce something ambitious for use by someone outside the classroom. This service-oriented approach, using web-based technologies, leads to innovative artifacts or performances. It emphasizes creativity to support learning, and learning to support creativity.

The foundational beliefs (Shneiderman 1998c) that led to genex's four phases were:

1) New knowledge is built on previous knowledge
2) Powerful tools can support creativity
3) Refinement is a social process
4) Creative work is not complete until it is disseminated

However, the social processes that were characterized narrowly as a support for refinement, can also be helpful at early, middle and late stages of the creative process. This paper more clearly defines the powerful tools that can facilitate creative acts. Furthermore, the close relationship of learning and creativity is more apparent. Combining the strategies in these two papers leads to a revised four-phase genex framework:

- Collect: learn from previous works stored in digital libraries
- Relate: consult with peers and mentors at early, middle and late stages
- Create: explore, compose, and evaluate possible solutions
- Donate: disseminate the results and contribute to the digital libraries

These four phases are not a linear path, creative work may require returning to earlier phases and much iteration. For example, digital libraries may be useful at every phase and discussion with peer and mentors may take place repeatedly during the development of an idea.

This four-phase framework has much in common with previous characterizations and methodologies, but there are important distinctions. Couger (1996) reviews 22 "creative problem solving methodologies" with simple plans such as:

- Preparation
- Incubation
- Illumination
- Verification

and this three-phase plan:

- Intelligence: recognize and analyze the problem
- Design: generate solutions
- Choice: select and implement

Couger offers his own plan with five phases:

- Opportunity, delineation, problem definition
- Compiling relevant information

- Generating ideas
- Evaluating and prioritizing ideas
- Developing an implementation plan

It is striking to me that so many of the plans limit themselves to the narrow perspective of the inspirationalists and structuralists. Problem solving and creativity are portrayed as lonely experiences of wrestling with the problem, breaking through various blocks, and finding clever solutions. The descriptions of even early phases rarely suggest contacting previous workers on this problem or exploring libraries for previous work. Consultation with others and dissemination of the results is minimally mentioned. Some reconsideration of such methodologies is in order because of the presence of the World-Wide Web. It has already dramatically reduced the effort of finding previous work, contacting previous workers, consulting with peers and mentors, and disseminating solutions (Kiesler, 1997).

Of course there are costs and dangers in reading previous work or consulting with others (Shneiderman, 1998c). There are also satisfactions in solving a problem on your own, but when dealing with difficult problems the benefits of building on previous work and consulting with peers and mentors can be enormous. The genex framework builds on the situationalists' perspective by embracing the expanded opportunities offered by the World-Wide Web (Berners-Lee, Cailliau, Luotonen, Nielsen, and Secret, 1994).

However, the need for improvements to the current World-Wide Web was revealed in a study of support for idea generation (Massetti, White, and Spitler, 1999). Twenty-three MBA students were asked to generate as many ideas as they could on three topics (robotics, societal change, and business opportunities in Ireland). In this within-subjects design, each subject was asked to use the World-Wide Web, categorical cues (five suggested categories), and no support. Subjects using the World-Wide Web did no better in generating ideas and did not have higher satisfaction. Categorical cues seemed to provide the best assistance, supporting the inspirationalist approach to stimulating creative ideas by guiding free associations.

The goal of genex framework is to suggest improvements for web-based services and personal computer software tools. By reducing the distraction caused by poorly-designed user interfaces, users's attention can be devoted to the task. In an effective design for a genex, the boundaries between applications and the burdens of data conversions would disappear. Data representations and available functions would be in harmony with problem-solving strategies. Then users could concentrate on the four phases of being creative: collecting, relating, creating, and donating.

4. Integrating Creative Activities

The revised genex framework calls for integrated creativity support tools. Some of these tools already exist, but could be enhanced to better support creativity. However, the main challenge for designers is to ensure smooth integration across these novel tools and with existing tools such as word processors, presentation graphics, email, databases, spreadsheets, and web browsers (Shneiderman, 1998a).

Smoother coordination across windows and better integration of tools seem possible. Just as word processors expanded to include images, tables, equations, and more, the next generation of software is likely to integrate additional features. Some aspects of the integration can be accomplished by creating compatible data types and file formats (possibly standardized objects). A second aspect of integration has to do with compatible actions and consistent terminology, such as cut-copy-paste or open-save-close. Higher levels of actions that are closer to the task domain might be candidates such as annotate-consult-revise or collect-explore-visualize. A third aspect of integration is the smooth coordination across windows (North & Shneiderman, 1997). For example, if users see an unfamiliar term they should be able to click on it and get an English definition, a French translation, or a medical dictionary report, all in a predictable screen location. Similarly, if users find a personal name in a document they should be able to get a biography, email address, or contact information. Other coordinations include synchronized scrolling of related documents to facilitate comparisons and hierarchical browsing of a table of contents and a chapter to enable easy navigation of large resources.

These improved user interfaces will benefit many users for many tasks, but my concern is specifically to develop creativity support within the genex framework. The three perspectives - inspirationalism, structuralism, and situationalism - each lead to useful suggestions for activities during the genex phases (Figure 1).

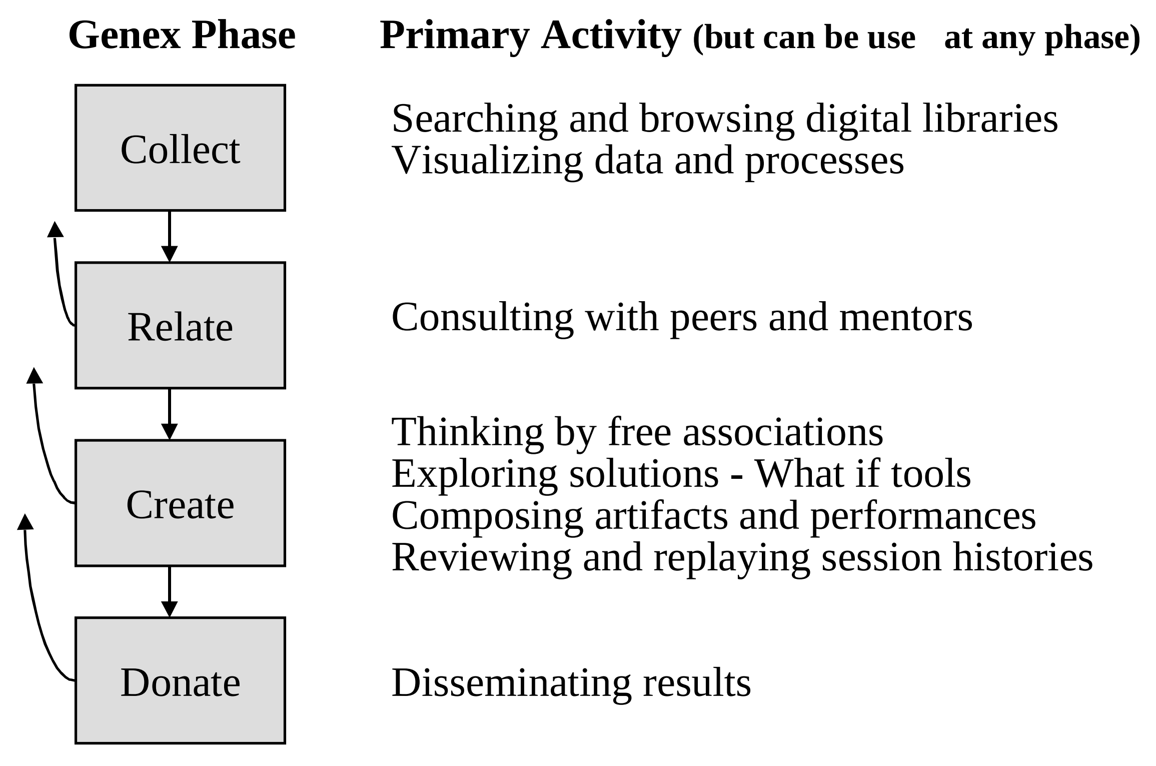


Figure 1: Genex phases and their related primary activities

Genex's integrated creativity support tools should offer at least the eight activities described below. Figure 1 indicates how these activities are primarily related to the genex phases, but these activities could take place during any phase. For example, searching of digital libraries is primarily associated with the collect phase, but searching may occur in order to find consultants or to decide on candidates communities for presenting of results. Visualizing objects and processes is the activity that seems most prolific and could appear in every genex phase.

Searching and browsing digital libraries: Existing web search engines and digital library interfaces do an impressive job, but refinements to support creativity are possible. Situationalist users who want to steer the search to resources about previous work will want more control over the relevance ranking and over the presentation of the results (Marchionini, 1995; Shneiderman, Byrd and Croft, 1997). For example, it should be easy for users to restrict a legal search to recent New York, New Jersey or Connecticut court cases on tenants rights for heating. The result set should be grouped by claims (civil rights, contract violation, etc.) and ordered by date with color-coded stars indicating the strength of the results for or against tenants. Extraction of plaintiff's or defendant's lawyers should also be convenient. This may sound like a tall order, but detailed search request specification while maintaining comprehensibility is possible. Since searching is part of a larger creative process the result set should be easy to save into a spreadsheet for further manipulation, or included in an email note for consultation, or pasted into a notebook for later referral.

In addition to searching, inspirationalists will want rapid browsing to more effectively support exploration, similar to what many people do in bookstores or libraries. Web sites with high branching factors (many links per page) support exploration by making what is available more visible. Yahoo's (www.yahoo.com) 100+ links on the home page are helpful in getting an idea of what is available and what is not. Browsing textual menus supports exploration when specific terms or concepts are not known. Imagine the complex request implied by this question: which strains of bacteria are causing recent flu symptoms for senior citizens in the Mid-Atlantic states? No specific search string could produce appropriate results, but browsing through search results may lead to exploration of viral infections, variant symptoms, other diseases, other locations, earlier epidemics, etc.

Information derived from searching digital libraries may provide the right results, but there are still many concerns about whether the information is accurate, complete, and up-to-date. Furthermore, online information may only be a fraction of the total information, and the search engines may search only a fraction of the online information.

Consulting with peers and mentors: Email, listservs, newsgroups, and threaded discussions are excellent asynchronous tools for situationalists' inquiries about previous work and for discussing new ideas. The capacity to find people who have a shared interest and are at work on similar problems is one of the greatest gifts of the internet. Synchronous tools, such as phone calls, videoconferencing (for example, CUSeeMe, Dorcey, 1995) and software sharing (for example Netmeeting), enrich the possibilities for early, middle, and late stage consultations (Olson and Olson, 1997).

For early stage consultations, innovators are likely to search widely, finding diverse information resources and broad communities. At this preparatory stage, innovators are forming questions, finding out about current workers who might be collaborators and choosing directions. During middle stage consultations, the tasks are to propose potential solution strategies and develop evaluation methods. As solutions are created and refined, late stage consultations are directed at confirming the innovation, refining it to accommodate criticisms, and then disseminating it to appropriate parties (National Research Council, 1993).

Consultations might involve continuing dialogs by email, phone calls, or personal visits. While these may often be collegial and friendly, some discussions might be tense since other workers may be competitors who are pursuing similar goals. Either party might withhold some of their knowledge or ideas, or probe the other to gauge their intentions. Non-disclosure or non-competitive agreements might be discussed or signed as part of a corporate consultation. University researchers are typically open, but the competition for solution of important problems and battles to promote reputations can suppress discussion.

These concerns greatly influence the design and use of technologies, since the appropriate balance of privacy protection and easy access to information is vital. Researcher's early notes and explorations need to be kept private, but claimed breakthroughs need rapid and broad dissemination. Appropriate credits for articles, patents, or software products are often the source of conflicts, so improved record keeping of the consultations that contribute to an innovation could resolve some questions and maybe encourage more cooperation.

Visualizing data and processes: While inspirationalists are likely to propose visual approaches, structuralists will also appreciate the thoroughness and rapidity with which alternatives can be reviewed using visualization. The field of pharmaceutical drug discovery involves review of thousands of compounds for their efficacy, shelf life, solubility, acidity, cost, allergic reactions, interactions with other medications, etc. Scrolling lists in spreadsheets are useful, but two-dimensional visual presentations with color and size coding are proving to be enormous benefits for this task. Early work on a FilmFinder (Ahlberg and Shneiderman, 1994) led to a successful commercial product called Spotfire (http: /www.spotfire.com) (Figure 2). A wide range of 1-, 2-, 3- and multi-dimensional visualizations plus temporal, tree and network presentations have been proposed (Card, Mackinlay, and Shneiderman, 1999).

Visualization of digital library contents, financial data, product sales, legal information, medical histories (Plaisant, Rose, Milash, Widoff, and Shneiderman, 1996), etc. is growing, but to increase its benefits to creativity requires smooth integration. The results of a web or database search should be easily imported (for example by cut and paste) into a visualization. Then users should be able to filter the data appropriately and adjust the visualization features, such as x,y-axes, color, size, or other codings. Then when an interesting group of items is found, users should be able to select them and paste them into a spreadsheet or statistics package for further processing. Then the visualization and processed items should be embeddable in a written report, slide presentation, or email note. Email recipients should be able to manipulate the visualization or report still further (Roth, Lucas, Senn, Gomberg, Burks, Stroffolino, Kolojejchick, and Dunmire, 1996).

Situationalists should also find use for visualizations in exploring digital libraries, locating key people, and presenting their findings to others.

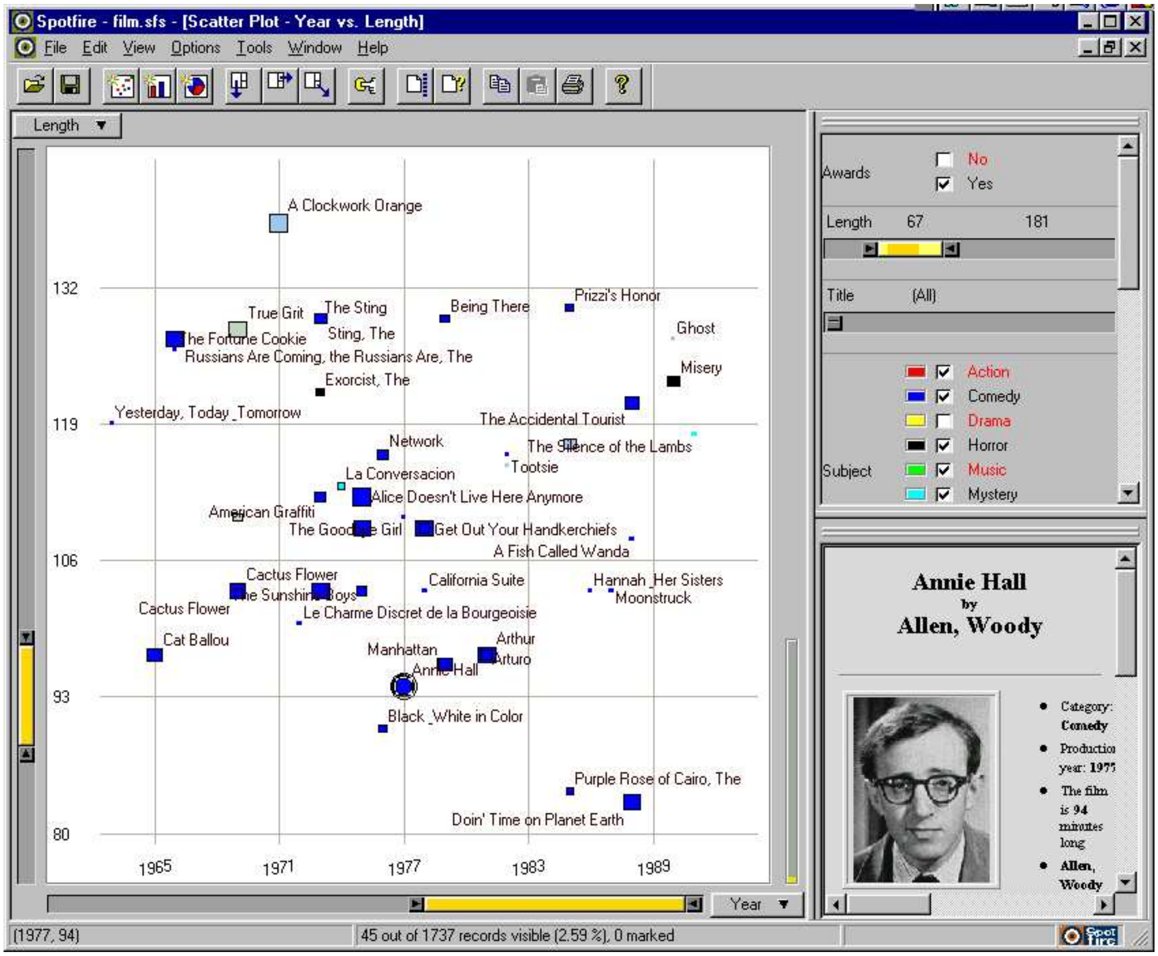


Figure 2: Multi-dimensional film database viewed with a 2-dimensional starfield display in Spotfire. The x-axis is the years and the y-axis is the popularity of the film. Color coding is film type (action, drama, mystery, etc.) and larger size dots indicate longer movies.

Thinking by free associations: Inspirationalists seek to liberate the mind by making free associations to related concepts. This Gestalt psychology approach (Mayer, 1992) has led to innovative software that is meant to facilitate association of ideas by presenting related concepts. IdeaFisher (http://www.ideafisher.com) claims "to create a new method of generating ideas in a way similar to the workings of the human mind...by associations, or links. ...a thought like food leads to associations such as apple, cooking, cafe, washing dishes, and so on. When a creative new idea is born, it usually consists of associations linked together in a way that has not been thought of before. This is the heart of IdeaFisher technology -- a dictionary of associations." Users apparently enjoy using IdeaFisher but its benefits are still being understood (Massetti, 1996).

Computerized thesauri may also be helpful textual exploration tools since varied associations such as synonyms, antonyms, homonyms, rhymes, or even anagrams can be retrieved rapidly. Alternatively, random word presentations are also proposed as a method for stimulating fresh thoughts and breaking through creative blocks.

Other products enable users to create visual representations of relationships among words or concepts, including MindManager (http://www.mindman.com/) which allows users to "create relationships among information easily... identify relationships between items or branches." The Axon Idea Processor (http://www.singnet.com.sg/%7Eaxon2000/) is promoted as "a sketchpad for visualizing and organizing ideas" that "exploits visual attributes such as: color, shape, size, scale, position, depth, link, icon, etc. Visual cues facilitate recall, association, and discovery. Diagrams and pictures help you to represent and solve complex problems." Typical mindmaps show a main idea in a central node and then branches in all directions showing related ideas (Figure 3). As the diagram spreads out the nodes and font sizes decrease so that many small details are shown. A popular alternative is to have the main idea at the top or left, and then have a branching tree structure going down or to the right.

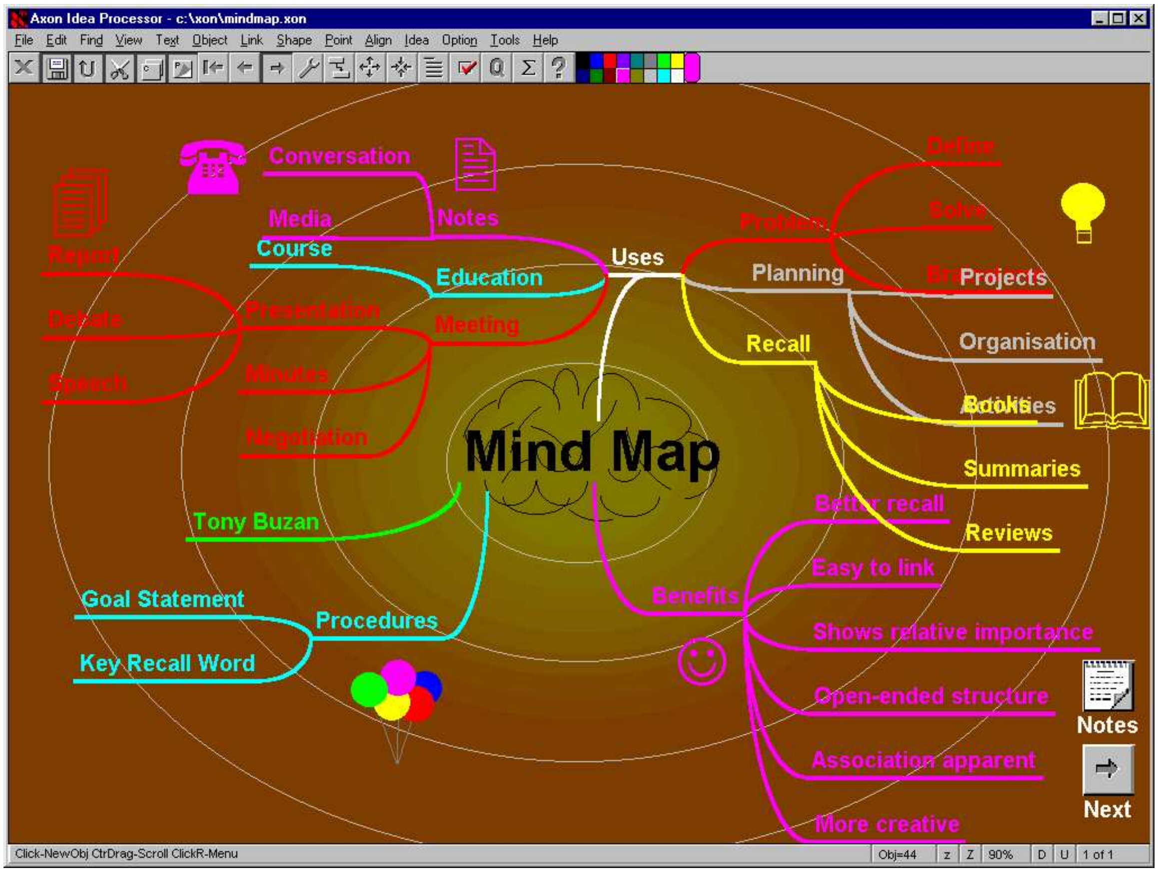


Figure 3: MindMap produced with the Axon Idea Processor

Mindmaps, concept maps, semantic networks and other drawing strategies may be helpful to some people. Appropriate visual presentations, such as the periodic table of elements, help in problem solving because they compactly present substantial information and show important relationships. Geographic maps, architect's drawings, and electronic circuit diagrams are other examples of the great power of visual presentations for learning and problem solving. The gift of the computer is the capacity to quickly create and easily manipulate such diagrams. Penciled diagrams and sketches have a similar capacity to invite discussion, exploration, and revision.

The genex framework reminds us that such textual lists and diagrams should be easily shared with others, annotatable, linkable, and searchable. It should be possible to import and export from these programs so that related tools can be employed, for example, to translate terminology in a diagram into a foreign language or to link diagram nodes to web sites.

Exploring solutions - What if tools: A large family of software tools already support methodical exploration of solutions in the structuralist style (Elan and Melissa, 1990). Electronic spreadsheets were quickly described as "what if" tools that allowed business planners and analysts to quickly try out a variety of scenarios. Such explorations were possible with paper and pencil, but they were a hundred times faster with electronic spreadsheets. Similarly, flight simulators, traffic flow models, weather models, and thousands of scientific, engineering, economic and other modeling tools allow users to explore alternatives safely, economically, and rapidly. Simulators have been largely custom built, but simulation building software is growing from domain specific to broader coverage. These simulation models are also becoming more richly featured to support explanatory text, collaborative usage, history keeping, and more (Rose et al, 1998, Simple). A popular class of home computer software include simulation games such as SimCity, that enable users to try out urban planning scenarios. Also popular with personal computer users are flight, driving, and battle simulators, that provide various levels of realistic experiences. These applications are enjoyable and also educational, however they are largely independent.

The genex framework and the situationalist perspective reminds us of the importance of integration to support creativity. Having run a simulation, can users save the whole session and replay it later to study their performance or discuss it with a peer or mentor? Can they send the session to someone by email, annotate steps, or search for key events or actions? Can excellent sessions be stored in a digital library to allow future researchers or problem-solvers to build on the best work?

Composing artifacts and performances: Another large family of software tools already supports creation of artifacts and performances. The ubiquitous word processor is the premier example of a flexible tool that enables many users to create diverse high quality printed documents using a relatively low cost laser or ink jet printer. Only a few decades ago such high production quality required advanced typesetting skills that were available to only a small number of people in the publishing industry. The word processor enables business people to produce elegant newsletters and professional advertising. It allows individuals to produce high quality resumes and elaborate full-length books. But word processors do more than facilitate quality appearance, they can also contribute to improved contents. The capacity to easily cut-and-paste, change terminology, or add references enables more people to create stronger scientific papers, legal briefs, or business proposals. It enables novelists, playwrights, and poets to easily accommodate suggestions from peers and mentors.

But even the word processor can be improved by thinking about creativity support in the genex framework. If new artifacts are inspired by previous work, then users should benefit from orderly processes for locating appropriate previous work and modifying it to suit their current needs. The basic notions of exemplars, templates, and macros, have already begun to appear. Authors of business letters can purchase thousands of exemplars that they can adapt in their own word processor. Then some of these authors might be able to contribute or sell their improved or specialized exemplars through growing digital libraries, available through the World-Wide Web.

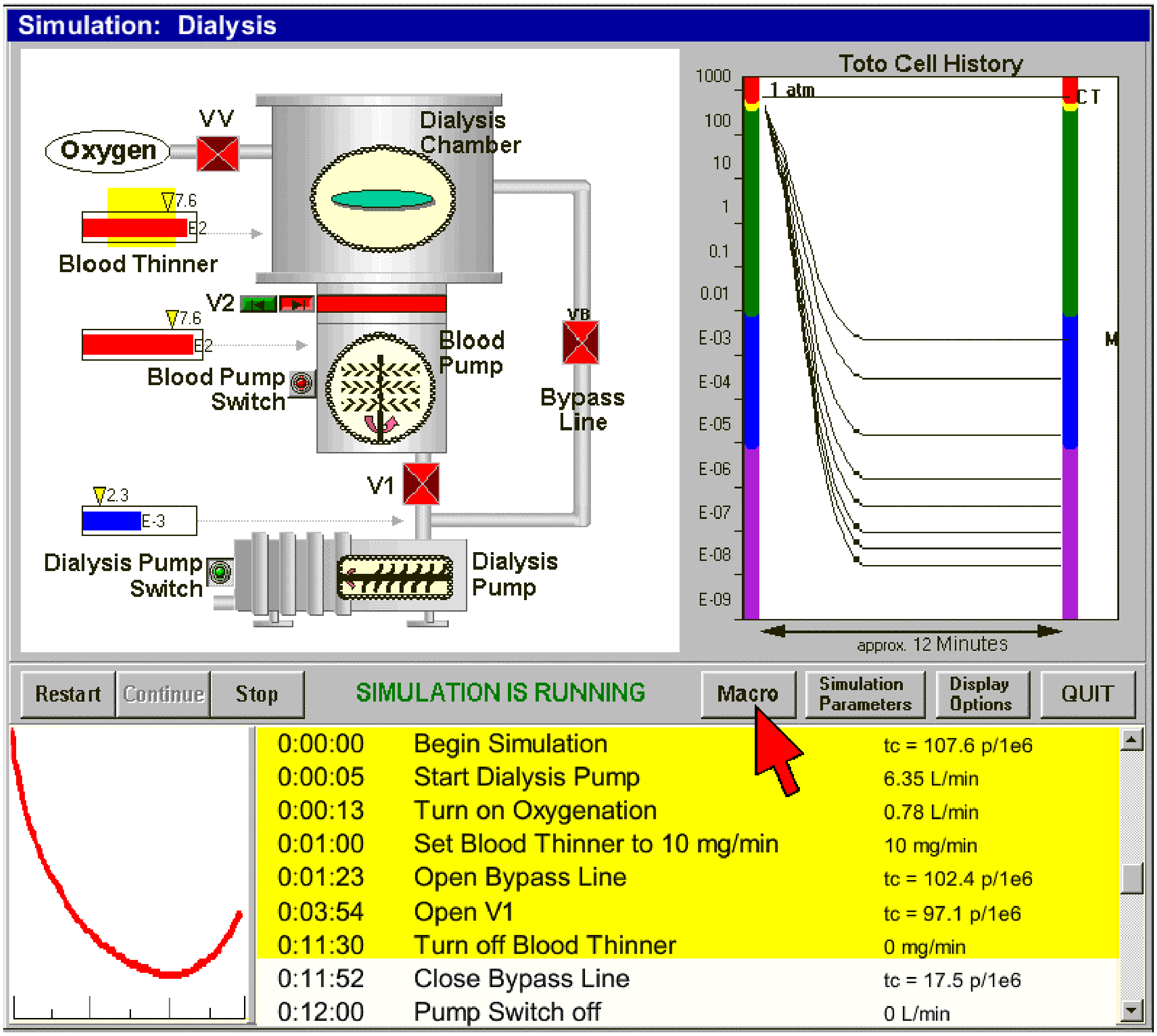
A more flexible strategy is to prepare templates, as is done for business documents such as invoices or travel expense reports. These are supplied with many word processors. Templates differ from exemplars in that they are somewhat more flexible, may include computational capabilities, and can have instructional guidance. Macros extend the flexibility and allow richer transformations of documents.

Making a wider range of exemplars, templates, and macros available and a mechanism to create a market in new ones are still needed. Microsoft Office contains templates for word processed newsletters, slide presentations sales reports, spreadsheet invoices, photo library databases, etc. The structured processes of users's choices, called Wizards, have been improved to give an overview of the steps for tasks such as generating a personal resume or a legal pleading.

Similarly, Adobe PhotoDeluxe provides excellent visual guides for the complex processes in getting, cropping, editing, annotating, and sending images. Adobe Photoshop offers useful macros for redoing images to give them the appearance of Van Gogh's bold brush strokes, Seurat pointillism, or other styles. Music composition programs also provide macros to transform a phrase or motif and generate New Orleans jazz or Rhythm and Blues pieces (www.pgmusic.com). Templates for fugues or sonatas and the capacity to recast motifs in the style of Brahms, Beethoven or other composers seem realizable.

Reviewing and replaying session histories: Reflecting on work is a central notion in quality improvement, creativity, and education methods. The metacognitive processes that promote self-awareness are learnable, but software support to capture the history of all user actions would seem to be a good foundation for many services. We have come to expect that web browsers record the history of our site visits, so that we can return to them. One study of World-Wide Web users showed that 58% of all URLs had been previously visited (Tauscher and Greenberg, 1997). Even in this simple case controversies abound because the strategy for producing a compact, meaningful list (in a linear, tree, or network format) is not apparent. Another problem is that web sites may change over time, so older histories may no longer produce the same results.

Producing histories of command lines in Unix or information retrieval programs is relatively easy, but understanding the meaning of each command may depend on the context (for example, the current directory). In richer graphical user interface environments such as simulators, image manipulators, legal information retrieval, or geographic information systems, recording each user step is feasible. However, success requires careful user interface and software design to ensure that the results are compact, comprehensible, and useful. Once these basics are accomplished, structuralists will especially like to manipulate session histories and replay the steps on another set of data or go back to change a step before replaying. Saving a sequences of steps for later use creates a basic macro, and by adding conditional and looping constructs quite ambitious programs could be built. For example, in a simulation of computer chip fabrication, it should be possible to rerun the simulation changing the temperature by single degree increments from 100 to 200 degrees Centigrade. If histories are first class objects then users should be able to send them to peers or mentors for comment or assistance with problems. Histories might also be searchable so that a set of hundreds of directories could be searched to see if any were done at a temperature above 200 degrees Centigrade. Users should be able to post or sell exemplars of excellence or macros that might be helpful to others.



0:00:00	Begin Simulation	tc = 107.6 p/1e6
0:00:05	Start Dialysis Pump	6.35 L/min
0:00:13	Turn on Oxygenation	0.78 L/min
0:01:00	Set Blood Thinner to 10 mg/min	10 mg/min
0:01:23	Open Bypass Line	tc = 102.4 p/1e6
0:03:54	Open V1	tc = 97.1 p/1e6
0:11:30	Turn off Blood Thinner	0 mg/min
0:11:52	Close Bypass Line	tc = 17.5 p/1e6
0:12:00	Pump Switch off	0 L/min

Figure 4: History keeping in the SimPLE environment (Rose et al., 1998). The user has run a simulation and produced a history, then re-run the history macro seven times to produce the seven outputs on the upper right.

Disseminating results: Email, listservs, digital libraries, the World Wide Web provide an excellent foundation for disseminating results but these also could be improved by thinking of the genex framework. The first circle of people to announce an innovation to would be previous and current workers. While digital libraries and online resources may make previous work accessible, extracting email (or mailing) addresses and ensuring that they are current is tedious, at best. Finding current workers in a domain is sometimes possible by listservs, newsletters, or websites of relevant communities.

A second circle of interest might be readers of papers or viewers of websites with related materials. Finding the identity of website viewers is not usually possible, but registration strategies might be developed to enable visitors to request information about future developments. The commercial bookseller amazon.com offers a service that will send you email when books on a topic or by a given author appear. Obviously, such registration lists have great commercial value, but publicly available variants are likely to emerge and be appealing because of their narrow focus. These are modern versions of what information retrieval professionals call selective dissemination of information (SDI), a policy by which users would be informed on a regular basis about new publications on topics they have selected.

Digital libraries could be reconceived of as digital library communities, by extensive use of online community software to turn every object into the focus of a discussion group. Anyone retrieving a novel, scientific paper, legal precedent, or classical music score could register to participate in a discussion of that item. Such online discussion groups would be a great stimulant to creative work in many disciplines.

Additions to scientific journals, music libraries, or art galleries would require review by editors, collections managers, and curators. Modern technologies not only speed up the process, but also facilitate review from multiple sources. Maybe more importantly the complexity and cost of establishing online journals, libraries, and galleries is substantially less than physical institutions, thereby lowering the barrier. Having more diverse institutions that create digital libraries is also likely to stimulate creativity.

5. Architectural Scenario

The genex framework and the eight activities could reshape many forms of creative work. Earlier genex examples included education, medicine, and legislation (Shneiderman, 1998c). The following scenario has some elements of wishful thinking, but it offers an example of how work practices could more easily support the genex phases of collect, relate, create and donate.

Imagine an architect, named Susan, who is called on to design a small hotel for hikers at a national park. She might collect plans for similar-sized hotels at other parks in the same region, or browse exemplars from anywhere in the world to get some ideas for alternative styles, such as Swiss chalet, Austrian lodges, or Rocky Mountain log cabins. Susan resizes and adjusts the building images to match the intended number of floors and rooms, then superimposes the images on the backgrounds of two potential sites: on the hillside and at the base.

The park managers and concessionaires who will run the hotel prefer the hillside site because of the wonderful views, rather than the base site. After consulting electronically with zoning commissioners and travel industry advisors, they choose the log cabin style since it best fits local and tourist tastes. Client input about the reception desk, a commons area with a fireplace, cafe, store, and guestroom dimensions shape the floor plan. A distinctive feature is the desire to support families and groups of hikers who wish to cook their own meals by providing communal kitchen/dining areas adjacent to the commons area. Preferences about views from the commons and dining areas influence changes in the design. In spite of the steep incline of the hillside site, engineering models enable Susan to prepare a structural design that is only 8% above the cost for the base site.

Then templates for room layouts enable Susan to rapidly make decisions about windows, insulation, and heating, while ensuring low energy consumption. Susan uses layout tools to ensure low-cost and easy maintenance for electric wiring, plumbing, smoke detectors, phone, and cable TV. She explores ceiling, wall decorations, flooring, and furniture choices with color and fabric variations. After a virtual walk through, the client requests larger windows, which is handled by reviewing the design history and changing the window sizes. This change causes rerouting of some wiring and an increase in solar-heating capacity, but the design is complete.

At this point, consultations begin with potential builders. Susan reviews the capabilities of builders and she receives bids based on the design electronically. Bill-of-materials lists for suppliers and a construction schedule are generated automatically for review by all parties. The construction proceeds rapidly and opening day is a triumph because of the long waiting list of families and groups who are attracted to the idea of cooking their own meals and meeting other hikers. Susan registers her design with the architectural society’s digital library and sends a description to interest managers of similar parks in her region.

6. Conclusions

Ambitious visions can be helpful in shaping more concrete research agendas. For example, Engelbart’s goal of augmenting human intellect (Engelbart and English, 1968) led to innovations such as the mouse and windows. Later, Brooks’s belief in the importance of toolmaking (Brooks, 1996) led to innovations such as haptic feedback in 3-d graphical environments. These inspirational visions were important catalysts for genex.

The ambition to support creativity led to the four phases of genex:

- Collect: learn from previous works stored in digital libraries
- Relate: consult with peers and mentors at early, middle and late stages
- Create: explore, compose, and evaluate possible solutions
- Donate: disseminate the results and contribute to the digital libraries

These four phases and the eight activities described in this paper

- Searching and browsing digital libraries
- Consulting with peers and mentors
- Visualizing data and processes
- Thinking by free associations
- Exploring solutions - What if tools
- Composing artifacts and performances
- Reviewing and replaying session histories
- Disseminating results

are major challenges but the integrated combination of them could produce an environment that greatly facilitates creativity. The eight activities and their integration form a research agenda for human-computer interaction and user interface design.

The goal of supporting more creativity by more people more of the time is attractive, but there is the danger that the genex framework might be ineffective or even limit creativity. By making easy access to previous work and current workers, there is a risk that more exotic ideas will be suppressed. Similarly, using creativity supports such as simulations and composition tools may restrict imagination to only what is possible with these tools. Consultations are time consuming, and discouraging advice for novel ideas is a possible outcome. Fear that others will plagiarize compositions or steal inventions is another legitimate concern. An understanding of the dangers is important in pursuing the positive possibilities.

Between the lofty ambitions and troubling fears, lies the practical path of careful research and detailed design for the eight activities described in this paper. They need development, testing, and refinement to making them successful, find their flaws, and pursue alternatives. At every stage, widespread participation in design reviews increases the possibility that the resulting technologies will serve human needs in constructive and positive ways.

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