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An Experimental Method for Measuring the Emergence of New Ideas in Information Discovery

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Although sometimes the task that motivates searching, browsing, and collecting information resources is finding a particular fact, humans often use information resources in intellectual and creative tasks that can include comparison, understanding, and discovery. *Information discovery tasks* involve not only finding relevant information but also seeing relationships among collected information resources and developing new ideas. The hypothesis presented here is that how information is represented impacts the magnitude of human creativity in information discovery tasks. How can we measure this creative cognition? Studies of search have focused on time and accuracy, metrics of limited value for measuring creative discovery.

A new experimental method is developed, which measures the *emergence of new ideas* in information discovery, to evaluate the efficacy of representations. The efficacy of the typical textual list representation for information collections is compared with an alternative representation, combinFormation's composition of image and text surrogates. Representing collections with such compositions increases emergence in information discovery.

1. INTRODUCTION

The creative intellectual tasks that humans perform with digital information resources must be supported and investigated. These tasks are critical to research, writing, learning, and invention on all levels. They are essential to business, education, and personal life. *Information discovery* tasks involve assembling information and connecting answers to open-ended questions (Kerne & Smith, 2004). Performing information discovery tasks requires finding elements of relevant information, collecting these elements, and developing an understanding of the found elements and their relationships. When people see combinations of found

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elements in new ways, they may experience cognitive restructuring, in which mental models shift and extend, resulting in the emergence of new ideas. Emergence, in the form of new ideas that come forth through novel combinations, is the essence of creativity, and the crux of discovery. The present research develops a new method for detecting and measuring emergence in answers to information discovery questions. We compared the efficacy of representations for presenting collections to participants and, in tandem, the representations that they used for putting together answers to information discovery questions. We found that compositions of image and text surrogates increase emergence in information discovery tasks.

Our long-term objective is to develop mixed-initiative support for information discovery through iterative design and development of the combinFormation platform (Interface Ecology Lab, 2007; Kerne et al., 2006). The platform functions as an extensible set of software components and interactive creativity support tools, which integrate searching, browsing, collecting, organizing, and authoring information in the mixed-initiative composition space. In the composition space, image and text information surrogates, each of which represents a document and enables access, are visually combined to represent the collection as a connected whole. Mixed-initiatives (Horvitz, 1999) combine user-centered direct manipulation with automatic and semiautomatic procedural agents that collect and compose relevant information.

When building complex systems, isolating the impact of components and independently assessing their efficacy is imperative. The objective of our research is to investigate the efficacy of combinFormation's composition of image and text surrogates representation. We developed an experimental information discovery task scenario, an apparatus, and a method for measuring the emergence of new ideas across experimental conditions. Our experimental apparatus included a direct manipulation-only version of combinFormation. All proactive agent components were turned off. Our central hypothesis was that the composition of image and text surrogates representation would increase emergence during the performance of information discovery tasks. In the experimental scenario, undergraduate psychology students answered open-ended information discovery questions about life experience. Each required applying principles of psychology, finding, assembling, and connecting multiple information resources, and annotating, to author the answer.

The experimental apparatus included a curated source collection of psychology resources. In one experimental condition, the source collection representation was a set of compositions of image and text surrogates that we had previously authored using combinFormation (Kerne, Smith, Choi, Graeber, & Caruso, 2005). To form answers, the students, none of whom had previously worked with composition, used direct-manipulation-only combinFormation to author annotated collections of information surrogates in the composition of image and text surrogates format. In the other experimental condition, both the source and answer collection representations utilized typical linear text.

This article begins with an interdisciplinary review of prior work, locating this research in the fields of creative cognition, information science, visual design, and human–computer interaction (HCI). We derive and extend measures of emergence from creative cognition research to comparatively evaluate the collections

developed by participants in the linear text and composition of image and text surrogates conditions. We describe the experimental method. We present and analyze results of the experiment, develop a perspective on different kinds of image-text surrogates, and then draw conclusions.

2. BACKGROUND

2.1. Creative Ideation: Emergence and Combination

Creativity has been a difficult concept to define precisely. In spite of the broad range of notions about creativity, a consensus has developed among creative cognition researchers that creative ideas and products must be novel in some way and that they must have value (Finke, Ward, & Smith, 1992). The creative cognition approach to understanding creativity focuses on the cognitive processes that underlie the production of creative ideas, processes involved in activities such as memory retrieval, visualization, categorization, problem solving, and analogical transfer. Of primary interest are the cognitive operations involved in *ideation*, the process of generating new and sometimes creative ideas. The creative cognition approach states that there is a family of features that are shared by most creative ideas, qualities such as insightfulness, imaginativeness, and emergence (S. M. Smith, Ward, & Finke, 1995). In our study, we focus on emergence in creative products, particularly as it relates to combinations of ideas drawn from digital information resources.

Emergence refers to qualities that come newly into existence typically as a result of novel combinations of elements (E. E. Smith, Osherson, Rips, & Keane, 1988; Wisniewski, 1996, 1997). Even when the elemental components themselves are not novel, new qualities that emerge from combinations comprise important creative discoveries in science, art, and business (Rothenberg, 1979; Thagard, 1984). Emergent properties can be seen in many domains. In chemistry, compounds can have properties that do not exist in any of the component elements; in visual perception complex objects can have emergent properties, such as three-dimensionality, which are not found in the feature-level components; and in language, words can have meanings that are not qualities of the component phonemes or letters. In the course of creative ideation, novel ideas often emerge when component ideas are combined. Combining concepts has been important in theories that deal with creative thinking, such as problem solving, idea generation, and insight experiences (Costello & Keane, 2000; Mobley, Doares, & Mumford, 1992; Mumford, Baughman, Maher, Costanza, & Supinski, 1997). A number of studies have shown that novel properties can emerge from conceptual combinations (Estes & Ward, 2002; Finke et al., 1992; Hampton, 1997; Wilkenfeld & Ward, 2001). These studies have primarily examined the cognitive processes that are involved when people comprehend combinations of concepts (such as *computer dog*), or when people imagine creative interpretations of ideas randomly combined by experimenters. The study presented here tests predictions and implications of these studies, examining the usefulness of a representational form that encourages and enables development of unusual combinations of information resources, particularly, combinations that have emergent properties.

Measures of creative ideation. Creative cognition researchers have observed that the cognitive components of creative thinking are different than those engaged in deductive reasoning (Finke et al., 1992; S. M. Smith et al., 1995). Thus, they have defined different tasks and measures to investigate ideation. Most prior research at the intersection of HCI and information retrieval has addressed *convergent thinking* tasks, which involve closed-form questions that have a single correct answer. A problem is explicitly specified, and the criteria for the solution are very clear. The accuracy of the answer, and the latency, or time to form it, are appropriate measures of performance.

To investigate creative ideation, *divergent thinking* tasks have been designed, in which one quests for many possible answers to open-ended questions (Finke et al., 1992; Shah, Smith, & Vargas-Hernandez, 2003). Divergent thinking tasks are objectively assessed with ideation metrics (Shah, Smith, Vargas-Hernandez, Gerkens, & Wulan, 2003), such as fluency (i.e., quantity of ideas), flexibility (number of different categories of ideas), originality (i.e., statistical infrequency of an idea), practicality/quality, and emergence (Estes & Ward, 2002; Estes & Glucksberg, 2000; E. E. Smith et al., 1988; Wilkenfeld & Ward, 2001).

Information discovery and its precursors. Creative cognition provides a valuable alternative perspective for considering parallel developments in the fields of information science and human computer interaction. The *information discovery* approach (Kerne et al., 2006) builds on berrypicking (Bates, 1989), anomalous states of knowledge (Belkin, 1982), psychological relevance (Harter, 1992), sensemaking (Baldonado & Winograd, 1997; Russell, Stefik, Pirolli, & Card, 1993), information foraging (Pirolli & Card, 1999), information seeking (Marchionini, 1997), and exploratory search (White, Kules, Drucker, & schraefel, 2006). Exploratory search, for example, addresses situations in which users "lack the knowledge or contextual awareness to formulate queries or navigate complex information spaces" or "the search task requires browsing and exploration" (White et al., 2006, pp. 10–13). Like others (Fisher, Erdelez, & McKechnie, 2005), exploratory search researchers have recognized that human information needs are not necessarily constant and convergent over the course of a search session.

Information discovery integrates concepts and methods from the prior investigations of human interaction with information with the creative cognition approach (Finke et al., 1992; S. M. Smith et al., 1995), to develop a human-centered framework. For example, changes in information needs represent not side effects but rather an essential stage in creative ideation. Information needs may shift as information is found, gathered, and re-cognized, when found information stimulates *cognitive restructuring*.

Information discovery investigates creative ideation in the context of processes and practices of information finding. In an *information discovery* task, the human goal is to have ideas in some area. This is a divergent thinking task in which information finding supports the generation and development of ideas. The context may be an academic task, such as paper writing or thesis formulation, or a life task, such as designing a vacation or a career. Search itself is not the task. Rather, search is a technology that supports information discovery tasks. We need to

understand and support more than how people find information. In information discovery, combining and understanding relevant information are as essential as search. The human need is to find elements of relevant information, collect and combine them, and develop a sense of connections among them. Found information can stimulate seeing new perspectives and formulating new mental models. This sets the stage for the emergence of new ideas. Therefore, to support information discovery, the research presented here investigates the role of the representation of the set of resources collected during an information discovery task.

Representing collections with composition. With the perspective of information discovery, we integrate the concept of surrogates, the power of image-text representations, and the form of composition to develop a new representation for collections. combinFormation supports developing collections by representing information with visual composition. A *surrogate*, such as the textual Google snippet, represents an information resource and enables access to that resource (Burke, 1999). People make critical decisions based on hypermedia surrogates, such as choosing which documents to browse and which to ignore. Building on extensive prior research (Baddeley, 1992; Carney & Levin, 2002; Ding, Marchionini, & Soergel, 1999; Glenberg & Langston, 1992; Glenberg, 2002; Mayer & Moreno, 2002; Wildemuth et al., 2003, Woodruff, Rosenholtz, Morrison, Faulring, & Pirolli, 2002), instead of using only text to represent a surrogate, we connect image with text. For assembling collections of surrogates, *composition* serves as an integrative alternative to lists and spatial hypertext (Marshall & Shipman, 1994). Composition means "the act of putting together or combining . . . as parts or elements of a whole" (*Oxford English Dictionary*, 1992). Our research builds on a prior laboratory study (Kerne et al., 2005), which showed that users subjectively experience composition as an easier-to-use representation for navigational collections.

combinFormation (Interface Ecology Lab, 2007; Kerne et al., 2006) is a mixed-initiative (Horvitz, 1999) system that enables humans to easily assemble collections of information resources as compositions of image and text surrogates. The participant and agents work collaboratively to develop the collection and its representation in a visual *composition space*. The system provides a set of direct manipulation facilities for forming, editing, organizing, and distributing collections as compositions. A field study investigated the role of combinFormation in the performance of 182 students in The Design Process course (Kerne et al., 2006). In the course, interdisciplinary teams of undergraduate students create new inventions. Students performed better on invention assignments when they used combinFormation to author a supporting prior work collection in the composition of image and text surrogates representation, than they did using popular search (http://www.google.com) and word-processing software (Microsoft Word) in the linear text representation. Use of combinFormation was found to promote information discovery.

What made combinFormation effective? We need to discover the role of different components of digital tools in supporting creativity. To create controlled experimental conditions, our research investigates the role of information representation. Thus, this study employs a reduced version of combinFormation, in

which only direct manipulation functionalities were available. Generative agent functionalities were excluded from the study apparatus.

3. EXPERIMENTAL METHOD AND RESULTS

We conducted a counterbalanced within-subjects study, in which each participant answered four information discovery questions. The independent variables were collection of information surrogates representation (text list vs. image-text composition) and psychology resources subcollection. We developed and applied the quantitative creative ideation measure of emergence. Another article reports results involving other experimental factors, including flexibility, quality, originality, and subjective participant experience reports (Kerne et al., 2007).

3.1. Participants: Undergraduate Psychology Students

Forty-three student volunteers participated in the experiment. Undergraduate students in the introductory psychology course, with enrollment of more than 100, fulfilled a requirement by participating. The experimenters were not personally familiar with the participants.

3.2. Information Discovery Questions

We designed study tasks to contribute to participants' education by pushing them to think creatively about the relationships between concepts in the field of psychology and issues in their lives. Each participant answered four information discovery questions:

- What kinds of things can cause behavioral problems for children in school?
- What psychological factors can influence a person's career choices?
- What psychological factors can influence a person's experiences dating? (See example answers, Figure 2.)
- What can cause obesity?

Participants were instructed to draw from the information resources source collection that we provided while developing their own ideas.

3.3. Information Resources Source Collection Representation

To provide source materials for the students engaged in the information discovery tasks, we curated a collection of information resources that represents six areas of the psychology curriculum: clinical psychology, consciousness, biopsychology, learning, developmental psychology, and perception. For each area, there are 6 to 10 information resources, each representing a subtopic. The collection comprises approximately 50 information resources. Each resource consists of a Web site or portion thereof, providing in-depth information on its subtopic. The

Web sites were downloaded and cached on a local server to eliminate the variability of network availability and latency.

The collection was split into two mutually exclusive subcollections to isolate experimental conditions and reduce carryover effects between tasks. Subcollection A was assigned the clinical psychology, consciousness, and biopsychology areas; subcollection B was assigned learning, developmental psychology, and perception. We developed navigation for each subcollection. At the top level, we assembled an overview consisting of one surrogate for each area. At the area level, we assembled 6 to 10 surrogates, each linked directly to an information resource.

To constitute the *information resources source collection representation* independent variable in the experiment design, we authored the overview and area level navigation separately not just for each subcollection, but further, for each of the two representation conditions: text list and image-text composition. Figure 1a shows the area level information resource navigation for biopsychology in the linear text format, and Figure 1b shows the biopsychology area level navigation for this in the image-text composition format.

3.4. Answer Representation and Interface

In each experimental condition, the participant used one of two interfaces to develop their answer using a particular information representation. Participants used the text form field of a web page to form the linear text answer representation. They utilized direct-manipulation-only combinFormation to form compositions of images and text. In this representation condition, the participant could select a passage of text and/or images from any information resource in the source collection, then drag it onto combinFormation and drop it into the composition space. Referentiality from the source Web page was automatically maintained by combinFormation in such cases, so that dragged-in material functions as a navigational surrogate. Participants also could use combinFormation to add their own ideas to the collected source elements, through annotation, visual design, and editing.

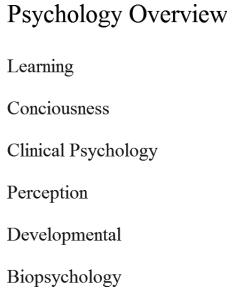

FIGURE 1A Area level information resources source collection navigation for Biopsychology: linear text representation.

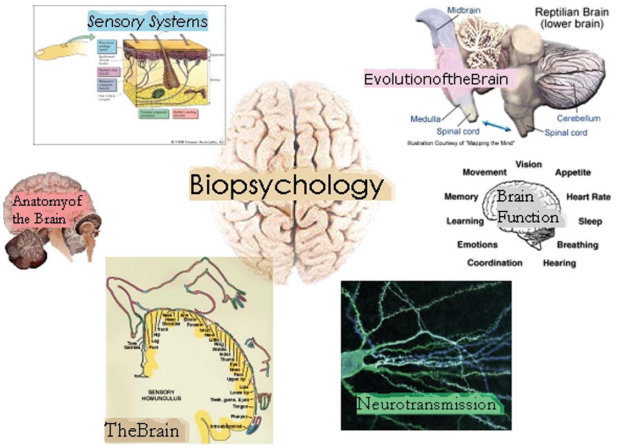

FIGURE 1B Area level information resources source collection navigation for Biopsychology: imate-text representation.

3.5. Experimental Conditions

Information resources source collection representation and information discovery question answer representation were grouped together into a single independent variable, *information representation*. Thus, for the composition of image and text surrogates representation condition, each participant encountered the psychology resources subcollection as an information composition and used the direct manipulation combinFormation to compose the answer with image and text surrogates. For the linear text surrogates condition, the participant encountered the subcollection as a list of text surrogates, and composed the answer using the text form field.

A 2×2 within-subjects design was employed. The two independent variables were information representation (image and text composition, linear text) and psychology subcollection (A: clinical psychology, consciousness, biopsychology; B: learning, perception, and developmental). Thus, the experimental design produced four different conditions over representations and subcollections: linear text representation with subcollection A, linear text representation with subcollection B, image and text representation with subcollection A, and image and text representation with subcollection B. Each participant was randomly assigned to one of the four conditions of representation and subcollection. Question order was counterbalanced between participants across these conditions.

3.6. Procedure

At the beginning of the experiment, each participant completed a short prequestionnaire. The experimenter introduced the direct-manipulation-only version of combinFormation. Participants practiced with the system. Instructions were given for the information discovery tasks. Participants were asked to do initial

research and author answers for several imaginary psychology course group projects by navigating the psychology resources source material collection. To author their collections of ideas, participants were told to browse Web sites that could help them develop answers to the questions and gather elements of information from the Web sites. Because their imaginary professor maintained strict antiplagiarism standards, they were instructed to include the Web address from which they obtained each information element. They were encouraged to create ideas by combining material from multiple Web sites and to form connections between related ideas. Creative and unique ideas were encouraged.

This was followed by the four information discovery tasks, each pairing a question with an experimental condition of information representation and subcollection. Participants were given 11 min to answer each information discovery question and were encouraged to use the whole time in composing the answer. Participants could see the time remaining counting down on a digital clock. Sixty sec before the end, the numbers turned yellow. Twenty sec before the end, they turned red. At the end of 11 min, if the participant had not clicked Submit, the program automatically submitted what they had authored.

3.7. Developing and Applying the Emergence Metric of Information Discovery

We developed a method for measuring creativity in the information discovery task scenarios. In doing so, we built on the prior work of Shah et al. (2003) in developing creative ideation metrics such as novelty and variety. Their approach includes a process of assessing components of each metric, developing rating criteria, and assigning human raters to invoke the criteria across a data set. Interrater reliability is measured to confirm the repeatability of the metric. Like the prior researchers, we are engaged in the difficult process of measuring the impact of experimental conditions on aspects of creativity. The human information discovery tasks of our research are even more complex than the engineering design tasks previously investigated, because we have variables that involve the role of different kinds of information representations and interactive interfaces. For information discovery, it is imperative to develop an emergence metric, because the focus in information discovery tasks is not just on listing ideas, but further, on seeing new relationships among them. *Emergence* means qualities come newly into existence as a result of novel combinations of elements.

To develop a process for specifying clear and concise criteria for measuring emergence, we defined a procedure such that multiple raters can independently and consistently score each participant response to each information discovery question. This requires defining criteria with sufficient clarity to achieve a minimum of difference between ratings from question to question, reviewer to reviewer, and study to study. As part of this, we defined a second criterion, *quality*. It was necessary to define quality as independent of emergence; that is, quality and emergence are orthogonal measures. Quality measures how well a student's response answers the question at hand. Emergence measures how elements are combined, in connection with the articulation of new insights by the

Table 1: Criteria and Scores for the Emergence and Quality Measures of Creative Ideation

	Score	*Criteria*
Emergence	0	The participant pulled elements from the assigned subcollection to answer a given question, but recognizable relationships and new ideas are minimal.
	1	Coherence between elements but not original or originality of elements but no coherence.
	2	Original and/or found elements in a coherent group.
	3	Original elements connected with found elements in a coherent group in a way that is clear and insightful.
Quality	0	Answer seems to have no relation to the question.
	1	Some relevance. Little or no explanation.
	2	Definite relevance. Some explanation.
	3	Wow, that was right on target. Very clear explanation.

student. Thus, the coherent grouping of elements was found to be a key characteristic of emergence.

Table 1 lists the criteria and scores that were developed for independently measuring emergence and quality. Each criterion is scored as an ordinal value from 0 to 3. For emergence, as coherence among grouped elements increases, higher scores are assigned. Further, interplay between found elements and original annotations indicates emergence when such contextualized annotation serves to develop and articulate novelty in combinations of elements, as per emergence's definition. Meanwhile, for quality, the characteristics of higher relevance of the answer to the information discovery question at hand, and higher clarity of explanation, are assigned higher scores.

3.8. Data

To illustrate how the emergence and quality were applied in context, we present a series of data examples. These are answers the students developed to the information discovery question, "What psychological factors can influence a person's experiences dating?" Figure 2 presents answers in the linear text representation condition, whereas Figure 3 presents answers in the image-text composition representation.

In Figure 2a, we see a cogent answer to the dating information discovery question. The answer is based on information about personality disorder from one of the source collection information resources. This answer was scored quality 3, for its extremely clear explanation, but emergence 1, because there is no combination of diverse elements. The answer progresses from a general introduction of a personality disorder to a more specific description of "Schizoid personality disorder," drawing relevant information from a single Web page in the source collection.

Figure 2b, another pretty good answer, is measured differently by the criteria. This response shows less quality but more emergence. The student

Influence of dating experience can be linked to clinical psychology. For example, personality disorders can have a great influence on the way that people interact with one another, and desire intimacy. A person suffering from Schizoid personality disorder often practices "detachment from social relations and very limited emotional expression in interpersonal settings." A direct result of this lack is a desire for any close or sexual relationships, preference for solitary activities, very little amount of friends, and indifference or aloofness. People with this personality disorder are not apt to date due to their lack of desire to have intimacy.

FIGURE 2A In a linear text format, a subject answered the dating information discovery question, "What psychological factors can influence a person's experiences dating?" This was scored as emergence 1, quality 3. The explanation is very clear and on target, but answer is entirely based on information from one information resource in the source collection.

Feeling is one's internal physiological state at any given point in time.

Emotion is the coming together of feelings and thoughts (prepositionally-based linguistic data) that are associated with the feeling.

Mood is the long-term emotion or the most representative emotion over a period of time. http://csdll.cs.tamu.edu:9080/study06_cf/Router/www. nwlink.com/~donclark/hrd/learning/theories.htmle.

Comment: The way that you feel about a person obviously influences your emotions. I believe that if someone is in a relationship and gets hurt by the other person, and changes their way of feeling and emotion toward dating, this could obviously alter one's perception of dating and would be more hesitant to start a new relationship.

FIGURE 2B Linear text answer to the dating information discovery question. This was scored as emergence 2, quality 2. The explanation about the psychological factors of dating is less clear than in the previous answer, but the answer incorporates the participant's personal perspective, in conjunction with reference information.

connects his or her own experience with material from the source collection, garnering an emergence rating of 2, because we see "original and found elements in a coherent group." However, the explanation is less clear, yielding a quality score of 2.

The example in Figure 3a was authored by a student performing in the image-text composition representation condition. However, this participant did not utilize any images. The participant obtained each of the three text elements here directly from the source collection, through drag and drop. The top two were drawn from the same Web site. The lack of diversity and comprehensible relationships among the found elements, despite their juxtaposition, results in emergence of 0. The relationship of the collected elements to the dating question is only suggested. It is vague. There is no explanation. The result is a quality score of 1.

In Figure 3b, we see how another student develops their answer. A chart with a timeline about sexual development by gender is juxtaposed with an annotation.

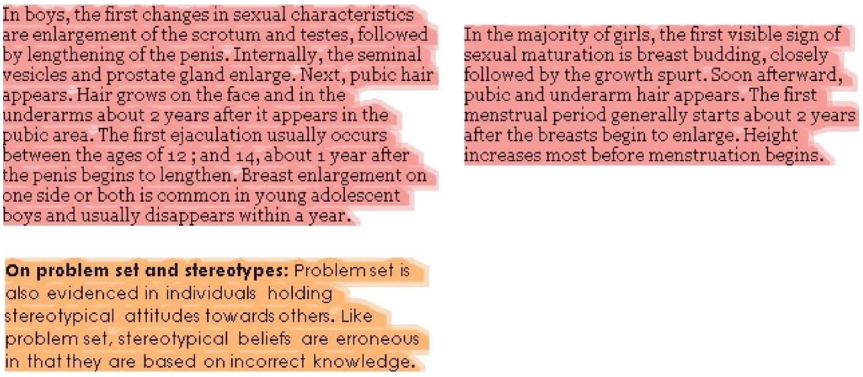

FIGURE 3A Composition of image and text surrogates representation answer to the dating information discovery question. We can imagine some relevance of these found elements to the dating question, but no explanation is provided, so the quality score is 1. The emergence score is 0 because there is no discernable grouping and no annotation explicitly representing the student's own interpretation.

The annotation develops a personal explanation of the chart in the context of the dating question. This was scored quality 2, emergence 2.

The student's work in Figure 3c shows the relationship between composition, emergence, and creativity most clearly. An abstract map of the brain is created by juxtaposing aspects of personality with brain areas. Material from four different Web sites is combined with annotations by the student. This highly coherent and insightful arrangement of diverse elements results in an emergence score of 3. As experimenters, we are excited by the expressiveness of this answer. However, despite the definite relevance to the dating question, the explanation is less clear, for example, than that provided in Figure 2a. Thus, the quality rating is only 2.

Once the experimental team had clearly defined the criteria for measuring emergence and quality, two raters scored all the participants' answers for the full set of questions. These results were then compared. The Pearson correlation between the two raters was 0.575 and it was statistically significant ($N = 170$, $p < .001$). To ensure correct ratings, the reviewers then met to resolve differences. Because the results were already quite consistent, this process was simple; a consensus dataset of ratings for emergence and quality was quickly developed.

We analyzed the consensus ratings dataset to measure the effect of the information representation condition on information discovery. Significant differences were observed for the emergence measure, across the collection representation conditions of image-text composition and linear text (Figure 4). The mean emergence measure was greater for the image-text composition representation (1.57) than for the linear text representation (1.01). This difference was statistically significant, $F(1, 42) = 4.73$, $p < .001$ (see Figure 3). The information representation condition includes both the information resources source collection and the representation of the answer that participants created to the information discovery

A psychological and physical factor that can influence a persons dating experience is puberty. Women tend to develop faster than man therefore they seek older males who have gone through their sexual development and therefore understand them more. Men on the other hand develop later and look for younger women because all the women their age are really looking for an older male.

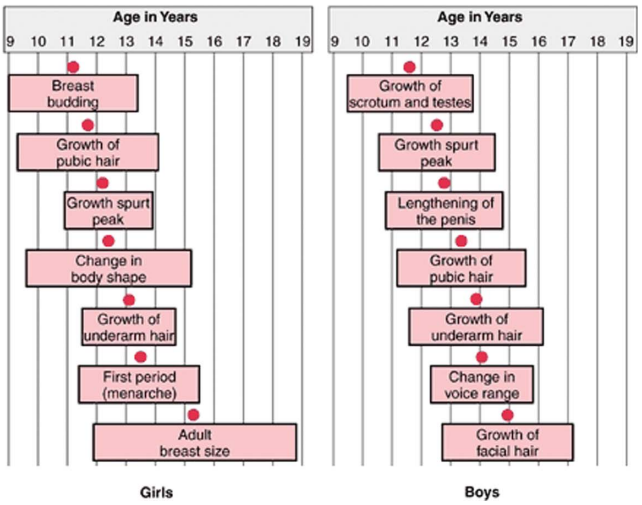

FIGURE 3B Composition of image and text surrogates representation answer to the dating information discovery question. This was scored as emergence 2, quality 2. This answer presents his/her idea about the psychological factors with the reference diagram. The idea is unique but does not cover multiple perspectives about dating psychological factors.

question. combinFormation's image-text composition representation was shown to increase emergence. There was no statistical significance across the collection representation conditions for quality.

3.9. Perspective: Image-Text Surrogates

Our research specifically compared the image and text surrogates created with combinFormation with linear text representations. combinFormation's image-text surrogates differ, for example, from the image-text surrogates of popular news Web sites (http://news.google.com, http://www.nytimes.com, http://news.yahoo.com). combinFormation's surrogates use overlapping and compositing to blend constituent elements. The news Web sites rely mostly on adjacency to arrange constituent elements to of their image-text surrogates. Further research can investigate whether these different image-text representations will impact emergence in information discovery. Although intuitively, blending would seem to be consistent with emergence, in practice we do not yet know if the difference will be measurable.

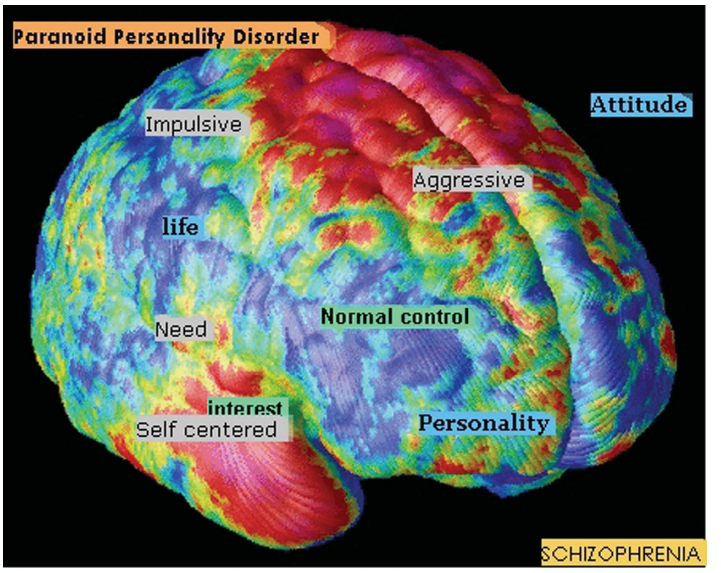

FIGURE 3C Composition of image and text surrogates representation answer to the dating information discovery question. This was scored as emergence 3, quality 2. This answer juxtaposes an interesting set psychological factors relating to dating with a picture of the brain, creating a sort of map. The juxtaposition is provocative and thoughtful, leading the viewer to think about how parts of the brain might relate to these issues in the dating experience. This is highly emergent. The explanation is, however, not super clear, resulting in the lower score for quality.

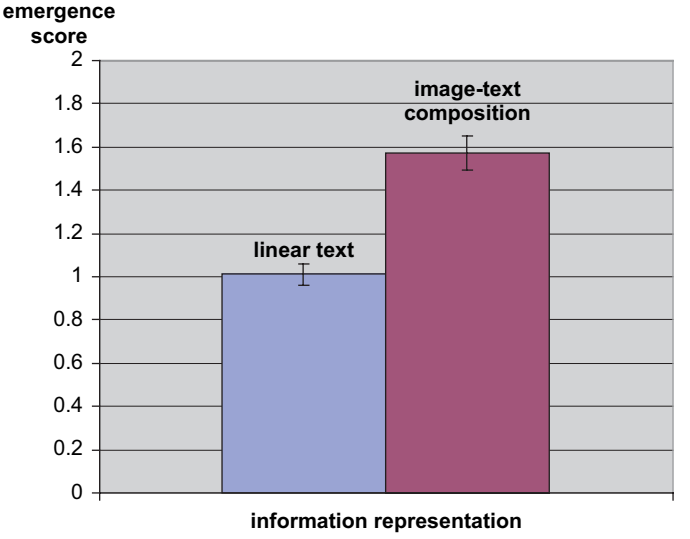

FIGURE 4 Experiment results: The mean emergence measurement scores (scale 0–3), according to the information representation condition. Image-text composition resulted in increased emergence.

4. CONCLUSION

The creative intellectual information discovery tasks and activities that humans engage in with digital information resources are critical to research, writing, learning, and invention. It is imperative for research that connects the fields of HCI, information science, information visualization, and information retrieval to develop tools that support creativity. This, in turn, requires the development of methods of evaluation for these tools. The discoveries that people make are of primary importance. Metrics such as time and accuracy are of little value. Some research focuses on qualitative experience reports derived through longitudinal case studies (Shneiderman & Plaisant, 2006). Our research develops and applies a quantitative metric for emergence. In the long term, like other researchers (Frechtling & Sharp, 1997), we are engaged a mixed method approach to evaluation.

We develop laboratory tasks to isolate experimental conditions involving information discovery. We build on the extensive base of prior creative cognition research to develop methods for investigating information discovery tasks in the laboratory, including reusable objective measures for evaluating creative products. The *emergence metric* measures the discovery of new ideas in conjunction with information finding. combinFormation, a mixed-initiative system for representing collections as compositions of image and text surrogates, is a complex program, in which direct manipulation components and generative agent components are interconnected. Rather than investigate the efficacy of the program as a whole, we constructed experimental conditions by giving users only the direct manipulation components of combinFormation, and collections we had preauthored. We isolated the variable of collection representation in the context of the performance of information discovery tasks. We applied the emergence metric to participants' creative products. This componentization of inquiry enabled us to address how information representation affects emergence. We found that composition of image and text surrogates increases participants' development of emergent ideas.

The quantitative information discovery measure findings developed through the laboratory experiment presented in this article are reinforced by other findings. Through an ecologically valid field study of undergraduate students in an interdisciplinary course on invention, mixed-initiative composition was found, through quantitative measures of students' performance, to improve flexibility, navigation, and an overall sense of creative experience in information discovery (Kerne et al., 2006). Qualitative data give insight into how the composition form promotes distributed creative cognition when students use composition to represent prior work collections in collaborative invention projects (Kerne & Koh, 2007). In all of these studies, and others (Kerne et al., 2005), most participants have preferred the composition to linear text representations and experienced composition as easier to use.

Over time, the evaluation of creativity support tools needs to employ and integrate diverse modalities of investigation, including laboratory experiments, ethnographies, field studies, and longitudinal case studies. Quantitative information discovery measures such as emergence need to be connected with qualitative data. Each modality makes different contributions. The present method for

measuring emergence evaluates the relationship of participants' answers to information discovery questions, which were authored while drawing from a provided collection of psychology resources. Future research will extend this emergence metric for application in less controlled task contexts, in which participants work with the Web's open-ended set of information resources. We will investigate the impact of other components of combinFormation, such as generative agent algorithms and interactive affordances, on emergence. We will develop, invoke, and connect emergence and other metrics for quantitative evaluation of information discovery tasks and activities with qualitative evaluation data.

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