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Creative cognition as a window on creativity

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Abstract

The creative cognition approach views creativity as the generation of novel and appropriate products through the application of basic cognitive processes to existing knowledge structures. It relies on converging evidence from anecdotal accounts of creativity and tightly controlled laboratory studies designed to examine the processes that are assumed to operate in those anecdotes. Specific examples of creative cognition studies are described in detail with a particular focus on research concerned with accessing conceptual information at varying levels of abstraction and combining previously separate concepts. Important aspects of the design of these studies are delineated, including the main creative tasks, properties of the materials used, characteristics of responses observed, including their originality and practicality, participant and rater attributes, and the relations among these and other study aspects. Other issues addressed are generality across materials, populations, and situations, as well as causal versus correlational connections among processes, structures and creative outcomes.

Keywords: Creativity; Cognition; Creative generation; Concept combination

1. Introduction

Creativity is a complex and multifaceted phenomenon. As such, it is appropriate to adopt a variety of methods to investigate it from a multitude of perspectives. The focus of the present paper is the methods associated with the creative cognition approach [1,2]. The approach adopts what has come to be a consensus view that creative products are characterized by two key properties; they are original or novel, and they are useful, practical or in some way appropriate to the task at hand. In the creative cognition approach, ideas and tangible products that are novel and useful are assumed to emerge from the application of ordinary, fundamental cognitive processes to existing knowledge structures.

This paper describes examples of creative cognition paradigms that are designed to gain information about conceptual processes and structures, and it delineates some of the critical design properties of such studies as well as their pitfalls and prospects. The goal is to provide guidance on developing studies concerned with the role of basic cognitive operations in creative performance. The intent is to discuss methods as opposed to more purely theoretical issues.

The methods described in this paper are cognitive rather than cognitive neuropsychological, although they are certainly amenable to enhancement via neuropsychological measurement, especially to the extent that any hypothesized cognitive constructs have theoretical correlates in brain structures, pathways, and systems see e.g., [3]. The perspective adopted here is that studies should be designed to be sound in a cognitive sense so that they then have the best potential to yield useful insights whether the main focus is strictly cognitive or more specifically cognitive neuroscientific.

2. A focus on underlying cognitive processes

The creative cognition approach is deeply rooted in its parent disciplines of cognitive psychology and cognitive science. It assumes that the cognitive capacity to behave creatively is a normative characteristic of humans, and it seeks to advance our understanding of creativity through precise characterization and rigorous scientific study of the cognitive processes that lead to creative and noncreative

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outcomes. A side benefit of the approach is advancing our understanding of basic cognitive processes by assessing their application in creative endeavors.

2.1. Beyond divergent thinking

Creative cognition seeks to move beyond traditional psychometric approaches to understanding creative thought, such as relying heavily on fluency and flexibility scores from *divergent thinking tests* as indicators of creative functioning. Many criticisms have been leveled at psychometric procedures, as detailed in other contributions to this special issue. However, from the perspective of creative cognition, the problem with an emphasis on divergent thinking is not so much that it is confused with creativity, for even researchers who use divergent thinking tests are careful to distinguish between creativity and performance on those tests e.g. [4], and others note that such performance is at best, a measure of creative potential not creativity itself [5]. Nor is the central problem that performance on divergent thinking tasks is unrelated to real world creativity, for there are some studies that do identify such links [4,6], albeit relatively modest links that do not account for large amounts of variance.

The major shortcoming of divergent thinking tests from a cognitive perspective is that divergent thinking is too broad a construct to provide a precise characterization of the processes that underlie creative accomplishment. When a person achieves a certain fluency score on a divergent thinking task by listing items in response to a prompt (e.g., alternate uses for a shoe), for example, the listed items may have been derived from the application of a wide range of processes, including episodic retrieval (e.g., recalling having used a shoe to kill a bug), mental imagery (e.g., scanning a mental image of a shoe, noting that it has laces, and realizing that they could serve a specific purpose), analysis of features (e.g., noting that shoes have the property of being heavy and therefore could be used as doorstops), abstraction (e.g., interpreting a shoe as a container, with the consequence that it could be used to store things), among many other possibilities. The point is not that any one participant uses all of these specific processes, but rather that it is the underlying processes that are doing the work and therefore are of most interest; the divergent thinking score is simply the end result. There is nothing wrong with using the score as an indicator, but a more precise characterization of creativity will require a detailed consideration of the processes that were used in generating the items that led to that score. By extension it is essential to come to understand the basic underlying processes that lead to all forms of creativity.

3. A convergence strategy

As a general guide to developing studies of creative processes, the creative cognition approach makes use of a convergence strategy [7,8]. Using that strategy, anecdotes or historical accounts of creative achievements or creative failures are examined to provide hints about potentially relevant processes and conceptual structures. Those processes and structures are then defined operationally in terms of experimental procedures and outcomes in a way that allows controlled experiments to be conducted to investigate them.

Combining anecdotes and laboratory studies helps to overcome the shortcomings of either approach alone. Anecdotes about real world instances of creativity are important because they point to processes that may have some ecological validity. On the other hand, being accounts of events that may have happened a long time ago, it is difficult to verify the extent to which particular processes were actually used and the extent to which they were causally associated with the real world accomplishments or failures.

Laboratory studies can be more effective in establishing causal connections between processes and outcomes, but they may create entirely artificial situations and assess processes with little or no relevance to real world creative endeavors. But, by basing laboratory investigations on processes and structures that are derived from anecdotal accounts, laboratory studies have a better chance of assessing relevant processes in reasonably valid ways.

Thus, using a convergence approach it is possible to balance the strengths and weaknesses of anecdotal and laboratory procedures against one another. The result can be a more compelling account of the cognitive underpinnings of creative accomplishment.

4. Examples of specific methods

Two types of processes will be used in this paper to illustrate the creative cognition approach: accessing existing conceptual knowledge at various levels of abstraction [9–11], and combining previously separate concepts [12–14]. However, it should be noted that a wide range of other processes have been investigated in creative cognition studies [1,2]. The presentation will include both anecdotal and experimental evidence.

In describing creative cognition methods relevant to these processes, examples of anecdotal information will be presented first followed by a description of the main issues that were examined in the related laboratory studies. Key aspects of the methods to be considered are the main creative task that the participants are asked to perform, associated procedures needed to assess and manipulate the stimulus materials, the populations from which participants are sampled, outcome variables that are used to indicate more versus less creativity or creative potential in the responses (e.g., ratings of originality and emergent properties), potentially relevant aspects of coders and procedures to increase trust in their ratings, generality across populations and materials, and other relevant design considerations.

4.1. Accessing stored knowledge at various levels of abstraction

Creative activities clearly rely on accessing stored knowledge, but some ways of accessing knowledge may be more conducive than others to the development of original ideas that diverge from those that have come before. In particular, I will describe work that examines the impact of accessing information at different levels of abstraction on the development of original and practical ideas.

4.2. *Preliminary anecdotal evidence of retrieval at specific concept levels*

Anecdotal evidence suggests that, at least for ordinary (as opposed to revolutionary) creative accomplishments people often access highly specific examples of solutions to earlier problems and pattern new solutions directly after them, a tendency that can facilitate a rapid solution but also impose constraints when unnecessary properties of known concepts are projected onto new solutions. Historical examples of this phenomenon abound, but a particularly interesting one is that, in the 1830s, when passenger rail travel was just getting started in the US, designers seem to have patterned the first railway passenger cars directly on horse-drawn stagecoaches, including the fact that conductors had to sit on the outside of the car [15]. This approach was efficient in the sense that railway passenger cars became available quickly, but because the conductors were seated on the outside, several of them fell off and were killed. Another example is that, according to Barker [16], Sony initially abandoned the development of music CDs because they started with LP record albums of the day as their model, and projected the property of a 12-inch diameter onto the envisioned new device. The device would have held a large and economically unviable quantity of music. Clearly Sony caught up and overtook many competitors, but the initial reliance on a highly specific known instance of a musical storage device slowed their early progress.

In the cases mentioned in the previous paragraph, accessing and relying on specific exemplars of earlier knowledge got in the way of innovation. However, there is ample evidence from historical accounts that many non-problematic advances in a wide range of domains also were based on a slow incremental process of patterning new ideas after very specific earlier ones, such as Eli Whitney's patterning his Cotton Gin after the charka and Thomas Edison's reliance on several previous designs to develop his light bulb see, e.g., [17,8]. That approach to the creative generation of new products may favor practicality over extreme, but impractical originality.

4.3. *Converging laboratory-based methods: creative generation paradigms*

To approximate real world creative endeavors of the type described in the previous section, researchers have devised several laboratory techniques in which participants are required to develop more complete creative products than in typical divergent thinking tasks. Such open-ended products have included collages [18], stories and drawings based on specific prompts [19], designs for novel toys [20], sketches and descriptions of possible extraterrestrials or other imagined entities [11], inventions for various domains [1], and logos for new products [21], among many others. The productions are generally rated for their creativity, originality, and practicality as well as for the presence of other specific types of properties. However, the ratings themselves are not the main issue. Rather, they are used primarily as markers to provide evidence about the combinations of external and internal factors that influence creative performance, as well as the cognitive processes and structures that are most commonly used and that are associated with more or less creative outcomes.

The particular example of a creative generation study to be discussed in detail was designed to test a path-of-least-resistance model [22]. According to the model, and as hinted at in the anecdotes described above, people will tend to approach creative generation tasks by retrieving one or more specific known instances of the relevant conceptual domain and projecting the properties of those instances onto their novel creation. Because the new products are constrained by specific properties of the retrieved exemplars, they are expected to be lower in originality than products developed by people who use alternative modes of processing. The retrieval and selection of an instance is assumed to be guided by the accessibility of instances within their categories, such that the higher the accessibility of a category exemplar, the more likely it is that the item will be used as a starting point in developing a new idea. For example, a person attempting to imagine a novel extraterrestrial would be likely to pattern the creature after a highly accessible Earth animal (e.g., a dog) rather than a less accessible one and rather than accessing more abstract information, such as "things that live on Earth," just as railway passenger car designers may have relied on the accessible "stagecoach" rather than a more abstract representation, such as "land vehicles."

Ward et al. [22] tested the assumptions of the path-of-least-resistance model across three conceptual domains: animals, tools, and fruit using data from *creative generation, listing, and rating tasks*. An important design feature to note is that the domains are relatively familiar to most people, so the studies could be conducted with a sample consisting of non-expert participants, in this case college students enrolled in psychology classes. Studies on creative generation for more specialized domains would necessarily dictate testing participants with at least some domain expertise. Another notable feature of the design is the use of three conceptual domains (rather than just one) to extend the generality of the results.

4.3.1. *Main creative generation task*

In the creative generation tasks, for each category, separate groups of participants conceived, drew and described novel instances that would be appropriate to an imaginary setting (i.e., animals or fruit that might exist on other planets, or tools an intelligent extraterrestrial species might use). They were given as much time as they desired.

4.3.2. Originality of outcomes and rating considerations

A dependent variable of central importance is the originality of the generated products. Because originality seems like a vague and highly subjective construct, it is essential to have more than one rater judge the responses and for them to achieve highly correlated ratings, and this was accomplished using two coders in the Ward et al. study.

One question that arises in choosing raters for creative generation studies is the extent to which their domain expertise matters. Although Amabile [18] began her work on the Consensual Assessment Technique with the assumption that judges should be domain experts, her results revealed that nonartists were as reliable as artists in judging the creativity of the collages she had her participants produce. Evidently, most people, even those without art training, have enough familiarity with the domain to make sensible judgments of the creativity collages. Similarly, most people have enough familiarity with animals, fruit and tools to recognize the extent to which a participant's creation deviates from typical instances of those domains so that they can render a reasonable judgment. On the other hand, as with the selection of participants for the study, if the domain under investigation is highly specialized, recruiting raters with specialized experience in the domain will be essential.

Another rating issue arises in studies in which comparisons are made across distinctly different groups for whom different assumptions may hold about what constitutes creativity. Niu and Sternberg [23] for example compared Chinese and American college students on a creature generation task and an art task. They used two Chinese and two American raters, and found that all the raters judged the originality of products by the Chinese students to be lower. Obviously, if they had used only American raters, the lower assessments of the Chinese students' products would have been suspect. In general then, in implementing creative generation studies, the appropriateness of the raters in relation to the participant population is of vital concern.

An additional factor that can lead to more trust in originality ratings, even ones that yield high interjudge reliability is to have more quantitative assessments of the participants' products. Ward, Patterson, and Sifonis [24], for example, calculated quantitatively-based difference scores for participants' imagined extraterrestrials. Points were assigned for each of seven major differences from typical Earth animals, such as no appendages, no sense organs, and violation of the property of bilateral symmetry. Although not reported in that study, correlations between the difference scores and raters' judgments of originality were large and positive, suggesting that the coders' ratings were indeed based on novelty in the sense of deviation from what is already known. In designing creative generation studies, thought should be given to whether or not objective deviation measures can be developed and what form they might take.

4.3.3. Assessing participants' approaches

In creative generation tasks, it is often of interest to gather evidence regarding participants' processing approaches, such as their retrieving of specific or more general types of conceptual information. In Ward et al. [22], subsequent to performing the creative generation task, participants wrote open-ended statements about the factors that influenced the development of their products. Because the study was focused on the issue of accessing and using highly accessible category exemplars, of particular interest in those statements were any reports of having used specific exemplars of known animals, fruit or tools as sources of information. *Imagination Frequency* was determined for each specific real world exemplar mentioned, and was defined as the number of individuals who mentioned relying on that particular exemplar in generating their novel idea. Imagination Frequency provides a gauge of the extent to which particular category exemplars are used in generating novel ideas for the domain.

One design consideration for obtaining information about participants' approaches in creative generation studies is whether to use retrospective reports as in Ward et al. [22] or online measures, such as collecting verbal protocols during the generation task itself. The former rely on memory, which may or may not be accurate, whereas that latter could conceivably disrupt the person's concentration on the creative task at hand. In using retrospective accounts, it is therefore helpful to have some independent measures to confirm those reports. For example, Ward [11] was able to correlate retrospective reports with the properties of drawings and show, among other things, that participants who mentioned relying on birds and fish were significantly more likely to produce creatures that had birdlike and fishlike properties, respectively, thus boosting confidence in the validity of such reports. As noted in the introduction, the focus in this paper is cognitive rather than neuroscientific, but if there are neural correlates of the processes under investigation (e.g., different patterns of activity for retrieving specific category instances versus more general category information), neuropsychological techniques could be integrated with such cognitive studies to provide confirming information about the mode of processing adopted.

Still another technique for assessing participants' approaches is to collect data on intermediate products. In their study on product logos, for example, Jaarsveld and van Leeuwen [21] had participants produce a series of sketches, which allowed them to assess aspects of generation such as introducing, abandoning, and reintroducing elements into the design.

4.3.4. Key property

One property of interest was the relative accessibility of the exemplars that participants reported relying on in developing their novel products. Accessibility was measured using a separate listing task, in which 30 participants who had not participated in the main study were given response forms containing a category label at the top and 20 blank lines beneath the label. They were instructed to write the first 20 real instances they could think of for each category. Measures of accessibility were determined from those lists, which were referred to as *Output Dominance*, defined as the number of participants who listed a given category member, and *Output Precedence*, which combined the frequency of listing with how early the items appeared on participants' lists. The listing task was not timed, but using a variation on the procedure (not reported in the paper) in which participants had 90 s to list as many category instances as they could think of led to comparable estimates of accessibility.

Norms for various key properties such as Output Dominance may exist in the literature, but because they can vary over populations and time of testing, it is generally preferable to collect norms from the same population and in the same time-frame as data from the creative generation tasks. Although more time-consuming, the approach increases the likelihood of observing the hypothesized relationships.

4.3.5. Connection between variables of interest and performance

Two related questions of interest are (1) whether, as hinted at by the anecdotal cases, a common processing tendency is to access and use specific known category exemplars, and (2) whether participants who do report a reliance on specific exemplars generate products that are less original, thereby indicating that their creativity is constrained by accessing those instances. The percentages of students who reported that they relied on their knowledge about one or more specific Earth animals, tools or fruit in developing their imaginary entities were 63, 68, and 66, respectively, indicating that accessing such exemplars is a common tendency used by roughly two thirds of the participants. Importantly, in each case, they produced creations that were rated as less original than those developed by participants who reported alternative approaches.

A more specific issue of interest in Ward et al. [22] was the extent to which Output Dominance, as assessed in the listing task, predicted Imagination Frequency in the creative generation task. Are the most accessible exemplars the ones most likely to be used in a creative task? The answer is yes. The correlation between the Output Dominance of domain exemplars and Imagination Frequency of those exemplars were positive and significant for all domains, $r(150) = .486$, $p < .01$ for animals, $r(201) = .615$, $p < .01$ for tools, and $r(79) = .622$, $p < .01$ for fruit. Instances that come to mind readily in response to a category label are the ones that are most likely to be used.

From an experimental design perspective, to determine correlations among the properties of the concepts people access (e.g., Output Dominance and Imagination Frequency) it is important to have a relatively large sample size. If the interest were simply in the overall tendency to rely on basic level instances or to determine relative levels of originality of people's creations, smaller Ns might be appropriate, but to examine links between key properties of concept instances and Imagination Frequency, larger Ns are necessary. This is because the likelihood of any one participant relying on any one specific exemplar (especially those lower in accessibility) out of the multitude of possible exemplars is small, making it necessary to have a large sample to obtain a range of values on the measure.

4.3.6. Generality

For the creative cognition approach (or any other approach) to provide important advances in understanding creative functioning, it is essential to document findings that generalize across materials and situations. The creative generation results reported by Ward et al. [22] were general in the sense that they applied to three distinct conceptual domains. They were also stable across instructional variations. For example, some of the participants were asked to imagine tools for a species that had no appendages, but those instructions reduced neither the percentage of participants who relied on Earth tools nor the correlation between Output Dominance and Imagination Frequency.

In addition, although investigators have not always assessed their participants' approaches to creative idea generation, the tendency of novel ideas to be structured in predictable ways by existing conceptual frameworks has been observed in a range of populations, including young children [25,26], gifted adolescents [27], science fiction authors [11], design engineers [28], and other creative individuals [8,29]. Thus, it is reasonable to assume that the tendency to retrieve and rely upon basic level domain instances is a common one, occurring across populations and domains of knowledge. More generally, it is clear that creative generation paradigms are broadly applicable to investigating creative functioning across a wide spectrum of populations.

Creative generation paradigms have also been devised to reveal the impact of recently experienced category exemplars. In these paradigms, exposure to particular exemplars results in the copying of properties of those exemplars even when participants are instructed to avoid doing so, as in the case of design engineers developing ideas for practical inventions [30] and college students imagining new toys and extraterrestrial animals [20,31].

4.3.7. Additional properties

An important concern in creative cognition research is being able to link particular aspects of people's stored concepts to creative generation outcomes. However, a complicating factor for any such study is that aspects of conceptual structure that are of interest may be correlated with others that are assumed to be less influential. Again using Ward et al. [22] as an example, although accessibility was hypothesized to be an influential property it may well be correlated with other properties, such as typicality or familiarity see e.g., [32], which could be the real determinants of performance. For example, when engaged in a creative generation task, people may prefer to rely on items that they are most familiar with, and those items may only coincidentally be ones that come to mind most readily. To examine that possibility, Ward et al. [22] had separate groups of 16–20 participants each rate exemplars on their typicality, familiarity, frequency of occurrence, and other properties. In collecting such ratings of stimuli or responses, it is important to have separate groups provide ratings to avoid having a person's rating of one factor (e.g., familiarity) contaminate his or her rating of another (e.g., typicality).

The ratings of the additional concept properties were used in multiple regression procedures, which revealed that Output Dominance continued to predict Imagination Frequency even when variance due to the other properties was accounted for. Finally, when variance due to Output Dominance was accounted for, rated typicality was significantly *negatively* correlated with Imagination Frequency, suggesting that those different aspects of representativeness may have functionally distinct roles in conceptual expansion. Output Dominance may determine the set of instances most likely to be retrieved and considered, and typicality may determine the items selected from that set, with people trying to boost originality by favoring the less typical among those highly dominant items. Thus, by considering alternative properties of stimuli and responses and using multiple regression procedures, creative cognition studies can yield new insights about the underpinnings of creative behavior. More generally, it is essential in any examination of the influential properties of the stimuli under investigation to consider whether there are confounding properties that might actually be the crucial ones.

A data analytic issue to consider in determining, which properties of a stimulus or responses are most influential is whether or not the measures of the various properties are on the same scale or are otherwise comparable. In the specific case of Ward et al. [22] for example, Output Dominance scores could range from 0 to the number of participants in the listing task (i.e., 30) and be heavily skewed, whereas familiarity, typicality, and other ratings ranged from 1 to 7 (because they were assessed via 7-point rating scales) and may be more evenly distributed. The wider range on one variable could give it an advantage in correlational analyses over those with smaller ranges. Consequently adjustments, such as log, square root, or other transformations may be needed to correct the problem and remove the advantage. In Ward et al. (2002), log transformations of the accessibility measures did not alter the outcome, but in general, that type of cautious data analysis plan may be needed to have confidence that favorable results are not simply an artifact of scale problems.

4.3.8. Practicality of products

The studies discussed so far have assessed originality, but not another key ingredient of creativity, namely practicality. A study by Ward [33] provides a cautionary note about the apparent value to originality of relying on abstract concept information as opposed to accessing specific exemplars. It may come at a cost to practicality. When college students were asked to devise new sports, although those who reported reliance on specific exemplars produced creations that were rated as less original (as in Ward et al. 2002), their creations were also rated higher on the extent to which people would actually want to play them. Thus, as implied in discussing the anecdotes for this section, at least some laboratory findings converge on the idea that reliance on known, highly accessible exemplars may limit the originality component of creativity, but enhance the practicality component. The findings highlight the importance of obtaining ratings of multiple properties of products in creative generation studies.

4.3.9. Causality

A crucial assumption in the creative cognition approach is that processes and the properties of conceptual structures are causally related to outcomes, which means that experimental manipulations of those processes and concept properties are needed. For example, accessing conceptual information at more versus less specific levels is assumed to be causally linked to differing levels of originality in participants' products. Ward et al. [24] provided evidence in favor of that assumption in a creative generation task in which participants in an exemplar condition were instructed to bring specific exemplars of animals to mind, others in an abstraction condition were told to consider general properties needed by animals to survive, and others (in a control condition) were given no special instructions. Rated originality was lowest in the specific exemplar condition, highest in the abstraction condition, and at an intermediate level in the control condition, thus providing evidence for a causal link between the approaches and the originality of the outcomes.

Similarly, to experimentally verify that accessibility of exemplars was causally linked to their use in creative generation tasks, Ward and Wickes [34] made use of the fact that the accessibility of category exemplars can be primed via preliminary orienting tasks, such as rating the pleasantness of category exemplars, which has been shown to increase their Output Dominance in subsequent exemplar listing tasks relative to exemplars that have not been rated in the preliminary task see e.g., [35]. Participants in Ward and Wickes [34] performed a pleasantness rating task with a subset of fruit and tool exemplars prior to creative generation. Exemplars that were rated in that task (as compared to exemplars that were not rated) had higher Output Dominance in a subsequent listing task (replicating the Graf et al. finding that the accessibility of the rated items had been primed). Most importantly, the rated items that were now more accessible also were higher in Imagination Frequency in a subsequent creative generation task in which participants imagined, drew and described novel types of fruit and tools, providing evidence for a causal role for accessibility.

Thus in addition to assessing processes and structures, an important item in the creative cognition toolbox is the experimental manipulation of those factors. Being able to support causal claims depends on such manipulations.

4.4. Combining previously separate concepts

A second process that has been of great interest in the creative cognition approach is conceptual combination, the mental merging of two individual concepts that had previously been separate in the thinker's mind. As with access to knowledge at different levels of abstraction anecdotal accounts and laboratory studies converge on important aspects of combining concepts.

4.5. Preliminary anecdotal evidence on the power of particular types of combinations

In anecdotal accounts, one of the most commonly noted processes underlying creative accomplishments is the combining of previously separate elements (e.g., words, concepts, visual forms, and so on) such that new properties, discoveries, or insights emerge from the combination that would not have been expected from a consideration of the separate elements. Whether in science, technology, art, music, literature, or other creative realms, combinations are touted as stimulants to creativity. To illustrate with just one example from literature, Stephen Donaldson, a noted fantasy writer attributed the inspiration for his series on Thomas Covenant, The Unbeliever to the combined concepts of *unbelief and leprosy*. Unbelief is an unwillingness to accept the possibility of alternatives to our observed physical reality. Donaldson had wanted to write a story about unbelief but was stymied until he combined that concept with the disease of leprosy, at which point his "brain took fire" [36]. The reason it was so powerful a combination for Donaldson is that his knowledge of leprosy told him that a person with leprosy would be extremely vigilant to detect unsensed, but potentially life threatening injuries and would be loathe to accept the reality of a fantasy world, even one in which he had a hero's status and apparent relief from the disease. The dynamic tension between Covenant's need for continued self vigilance and the attraction of the fantasy world sets the stage for a powerful series of books.

Donaldson went on to note that combinations of exotic and familiar concepts were particularly potent for him, echoing the view from other historical and anecdotal observations that discrepant and even opposing combinations hold the most potential for creativity see e.g., [37]. A question for creative cognition is whether or not the power of combinations, particularly those composed of dissimilar or opposing pairs, to produce emergent ideas can be demonstrated in a laboratory study with non-expert participants.

4.6. Converging laboratory-based methods: conceptual combination paradigms

A wide range of laboratory studies have asked participants to define, interpret, list properties of or otherwise process novel or familiar combinations or conjunctions of concepts. Although many of the studies have been concerned primarily with language processing, a persistent phenomenon relevant to understanding creativity is that emergent properties appear in the combinations that were either non-evident or completely absent from either of the constituents of the combination. So for example, Harvard educated carpenters are sometimes deemed to be non-materialistic, whereas neither Harvard educated people nor carpenters alone are so characterized [38]. Likewise, culturally anomalous combinations, such as Republican social worker [39], and truly exotic conjunctions, such as furniture which is also fruit [13] lead to emergent properties not characteristic of the separate elements of the combination. One interpretation of the findings is that participants have to generate explanations or otherwise reconcile the discrepancies of the component concepts, which leads them to postulate novel properties. Although these studies did not require participants to develop stories, much like Donaldson's "unbelieving leper," the more discrepant combinations seem to suggest more creative possibilities than more stereotypic combinations (e.g., Harvard educated lawyer).

An example of a conceptual combination study that more directly tested the role of constituent similarity in producing emergence that will be describe in more detail here is Wilkenfeld and Ward [40]. In that study, participants interpreted combinations that varied in similarity and the number of emergent features was assessed.

4.6.1. Main combination task

The college student participants were given 16 pairs of words and asked to write two separate definitions of each. Eight of the pairs were composed of similar concepts (e.g., guitar harp) and eight were composed of dissimilar concepts (e.g., airplane puddle). Because definitions alone would not be expected reveal a large number of attributes that people deemed to be true of the combined concepts, participants were also asked to list features that something would need to be considered a good instance of the defined concept. The set of features could then be used to determine whether there are novel properties that emerge from combining the concepts and whether they are more pervasive in dissimilar combinations.

Although experimenters could probably construct similar and dissimilar pairs for this type of study based on their own intuitions, a better approach, and that used by Wilkenfeld and Ward is to verify intuitions through similarity judgment tasks. Thus, the 16 pairs that were actually used in the main task were selected from a set of 90 pairs (45 assumed by the experimenter to be similar and 45 assumed to be dissimilar) based on similarity ratings provided by a different group of participants. The 16 pairs actually selected were the 8 most similar and least 8 similar pairs based on those ratings.

4.6.2. Emergence properties of the combinations

Rather than ratings of originality as in creative generation tasks, the measure of the creative outcome in this type of study is the number of emergent properties. Operationally, emergent properties are those that are evident in the definitions and feature lists for the combinations but not in feature lists for the separate concepts. To provide the needed features for assessing emergence, a separate group of participants listed the characteristic features of each of the separate concepts that comprised the 16 similar and dissimilar combinations. The participants were asked to list at least six features that describe each word. They were further instructed to avoid purely personal or idiosyncratic free associations to the words. Without such an admonition, feature listing tasks can lead to large numbers of associations unique to each individual (e.g., for guitar: "I once dated somebody who played guitar in a band") rather than the more characteristic features that are generally true of the objects themselves (e.g., for guitar: "six strings"). However, even those features mentioned by only one person were noted in order to produce a list of features of the component concepts that was as comprehensive as possible. The resulting database contained more than 11,000 features.

Features were considered to be emergent if they were in the list for a combination but not for either of its constituent concepts alone. An alternative approach that could be used in studies of emergence is to present participants with lists of features to be judged in relation to single and combined concepts and to consider features to be emergent if participants judge them to be true of the combination but not of the constituent concepts alone [13]. The listing and rating procedures have been found to yield comparable results [38,39], so either could be used, but the former may be more appropriate for truly novel combinations that are likely to evoke a range of idiosyncratic interpretations, whereas the latter may be more appropriate in a study involving familiar combinations for which most people will share the same interpretation. If one person interprets the novel combination of "airplane puddle," for example, as "an oil slick under an aging plane" and another interprets it as "a pond for landing a seaplane" they would not be expected to agree on judgments about possible features of the combination such as "dirty" or "slippery." Thus, rather than obtaining group ratings of the validity of features, considering all features listed by each participant to be valid features of the combination would be appropriate. In contrast, for familiar combinations such as "pet bird," for which there is likely to be a consensus definition (e.g., a real bird that is also a real pet in the ordinary sense), using consensus ratings of whether properties (e.g., "lives in a hanging cage") are true of the combination would be a viable option. If most people then judge "living in hanging cage" to be true of "pet birds" but not "pets" or "birds" in isolation, that property could be deemed to be emergent for the combination.

Consistent with the anecdotes mentioned at the beginning of this section, Wilkenfeld and Ward [40] found that dissimilar combinations resulted in more emergent properties than similar combinations. They also found that second interpretations resulted in more emergent properties, especially for similar pairs, indicating that people may use up their easiest interpretation first and then engage in more creative exploration to produce a second interpretation. Thus, the laboratory results confirm and extend the anecdotal accounts.

4.6.3. Additional properties

As in the creative generation studies, in focusing on one property of interest, it is essential to consider whether it is confounded with other properties that may be of less interest, but are nevertheless influential. As an example of controlling extraneous factors, all of the concepts in Wilkenfeld and Ward were non-living. In fact, one dissimilar pair, "snowmobile bass" was not included in the final set because participants interpreted "bass" as the fish rather than the musical instrument as intended. If living things had also been included in the materials, it could have been that the dissimilar pairs ended up being composed of one living and one non-living thing whereas the similar pairs might be from the same ontological categories. Difference in emergence might then be based on ontological category membership in particular rather than global similarity in general. Thus, care must be used in creating pairs that are assumed to vary in similarity or other properties for this type of conceptual combination study.

4.6.4. Generality and variations

Although the relative similarity of component concepts is important to emergence, anecdotal suggestions indicate that opposition, or Janusian thinking may also be important [37]. A study by Estes and Ward [41] brought opposition into the laboratory by assessing emergence in opposing versus non-opposing concepts (e.g., friendly enemy and complex simplicity versus hostile enemy and clear simplicity). Consistent with anecdotally-based expectations, opposing concepts yielded more emergent properties.

Combination processes also include more than just interpreting noun–noun or adjective–noun combinations, and laboratory studies have been devised to examine various combinatorial processes. For example, sometimes combination involves figuring out how to integrate sets of objects that ordinarily are not grouped together into a single coherent concept. Mobley, Doares, and Mumford [12] used a paradigm to approximate that type of combination process, in which participants were given four exemplars from each of three categories (e.g., furniture: chair, couch, table, and stool) and had to develop concepts to explain the grouping of all of them together. When the component objects were more dissimilar, people generated more original outcomes, but the outcomes were also judged to be of lower quality. As with studies in the creative generation section of this paper, the findings point to the need for ratings of products along multiple dimensions, including the key creativity ingredients of originality and practicality.

Creative combination processes that operate in real-world setting go beyond combining simple concepts and can include combining larger knowledge structures. Importantly, Scott, Lonergan, and Mumford [42] have also shown that this type of paradigm can be extended to examine combinations of more complex structures. In that study, college students were asked to combine information from descriptions of education programs to develop their own ideas for curricula.

Sometimes combinations can be of visual forms as opposed to verbal concepts, as in Tesla's envisioning of the integrated workings of separate components of devices. To investigate image-based combination, Finke [43] developed a procedure in which participants were given sets of three geometric forms and were asked to mentally integrate them into more complex ones that could be interpreted as inventions or new products for domains, such as furniture, vehicles, or tools (see also [44]). When subjects chose the category or were assigned a category in advance of generating the form, they produced fewer creative inventions (rated as original and practical by judges) than when the relevant category was specified only after they developed the forms. There seem to be creative benefits of combining visual materials without a specific goal in mind and then later interpreting them in an exploratory phase of processing.

5. A multitude of applications

The studies selected for review were presented in detail to illustrate important issues to be considered in designing creative cognition studies. However, there are many other basic types of processes that underlie creativity that have been investigated in creative cognition studies, such as analogy e.g., [45,46]. The Gentner et al. [46] work is especially interesting in the sense that it used the convergence approach described here in reverse. They analyzed the historical account of Kepler's reasoning about planetary motion, not to devise new experiments that would converge with and confirm his account, but rather to show how Kepler's account converged with and lent real-world, extreme-case validity to existing laboratory research and theorizing about analogy. Analogy is a global descriptor for more fundamental processes such as alignment, retrieval, mapping, and projection of information from a source to a target domain e.g., [47], and Gentner et al. were able to show how specific aspects of Kepler's reasoning fit in with that detailed model of stages in analogical reasoning.

Dunbar's approach [45] represents advances on several fronts, including the fact that he assessed cognitive processing in groups (rather than just individuals) through analyses of molecular biology laboratory groups. He identified limitations of anecdotal accounts of far analogies in creative discovery (e.g., solar system: atom), by showing that ongoing groups only rarely use such analogies for discovery. Noting when laboratory findings fail to confirm expectations based on anecdotes is as crucial to understanding creativity as identifying when they do. Finally, Dunbar identified a wide range of cognitive processes other than analogy, such as reasoning about unexpected findings that should receive attention in creative cognition work.

Other researchers have shown how traditional cognitive psychology approaches can be adapted to analyze creativity relevant processing topics such as the role of memory and forgetting in incubation and insight [10,48,49], intuition [50], the importance of problem finding and problem definition [51–53], among many other processes.

6. Summary and conclusions

An important feature of the creative cognition approach is the specificity with which it characterizes both the nature of basic cognitive processes and how they operate on knowledge structures to produce original and task-appropriate ideas. Rather than relying solely on global cognitive descriptors, such as "divergent thinking," a creative cognition approach seeks to specify the basic component process that lead to divergent productions, such as retrieval, combination, analogy, and so on.

Creative cognition studies generally begin with anecdotal accounts that highlight seemingly relevant processes, structures and other considerations. In designing laboratory studies to converge with (or possibly disconfirm) the anecdotes, it is necessary to consider a wide range of factors. These include the task to be performed, the nature of the stimuli to be used and the manner in which they are presented. They also include any additional properties of the stimuli that are not of central interest, but might nevertheless influence performance. Beyond the task and stimuli, it is also essential to clearly define the specific process or set of processes under investigation, the types of products to be developed and the properties they possess, such as rated originality and practicality along with other indicators of creative potential such as the emergence of novel properties. Other issues of importance are the causal, as opposed to purely correlational links between processes, structures and outcomes, the generality of findings across populations, materials, and situations, as well as the characteristics of raters and populations such as their domain expertise and cultural backgrounds. The fine-grained assessment of basic cognitive processes in the creative cognition approach is an important tool in coming to fully understand creativity.

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