Cognitive Antifreeze: The Visual Inception of Fluid Sociomaterial Interactions for Knowledge Creation

Lawrence McGrath

Abstract This pilot study investigates the idea generation process of ad-hoc pairs using external visualisations for divergent thought. The study's objective is to examine if pairs' perceived possibility to change the external visualisations of their ideas affects how deeply they explore cognitive categories. The depth of cognitive category exploration is known as cognitive persistence. A 2 x 2 factorial experiment with active middle to upper level management participants was employed. The experiment operationalised the perceived changeability, or fluidity, of visual objects through manipulation of pairs' worksheet template and writing instruments. For the writing instrument, pencils operationalised high perceived changeability, and pens operationalised low perceived changeability. For the worksheet template, blank sheets operationalised high perceived changeability, and pre-printed mindmaps operationalised low perceived changeability. The results indicate that a sociomaterial interaction impacts upon participants' cognitive persistence. This study finds that cognitive persistence is highest amongst pairs using a consistently high perceived changeability pencil/blank worksheet combination. Conversely pairs using a high perceived changeability pencil with a low perceived changeability pre-printed mindmap display the lowest cognitive persistence. The materials pairs note ideas with together influence their need to seize upon an idea. Such seizure reduces cognitive persistence. Fluid visual representations function as an effective cognitive antifreeze.

Keywords Creativity · Dyad · Visualisation · Perceived finishedness · Cognitive persistence

1 Introduction

It is widely known that knowledge creation [1] is crucial to competitive advantage across fields [2]. How to reliably surface effective, efficient knowledge creation is far less well known. This pilot study examines sociomateriality as a means by which to

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increase the cognitive persistence of creative pairs in an effort to dependably enhance knowledge creation.

2 Literature Review and Hypothesis Development

The research concentrates on whether the degree of perceived finishedness of the graphical representation of a dyad's joint problem solving space influences its tendency to exert cognitive effort on divergent thinking.

2.1 Dyads

Until recently, dyads were largely overlooked in the field of knowledge creation. However, interactive groups formed via the combination of dyads [3] have now been shown to creatively outperform nominal group technique [4] as a function of lowered evaluation apprehension [5]. These findings on group creative process optimisation via dyadic structures create a new imperative to optimise dyadic ideation.

The creativity literature on dyads is sparse, but encouraging. In 1960 Cohen et al. [6] found cohesive, trained dyads to be creatively efficient and effective; and this study positioned cohesion as the key success factor for dyads in creativity. Soon after Cohen, Whitmyre and Funk's work, Janis' influential 1971 work on groupthink [7] began emerging and creativity research on dyads became resultingly sporadic at best. Two years after the second edition of Janis' book Groupthink [8] was published, Pape and Bölle's conclusive demonstration of higher fluency results for ad hoc, untrained dyads than pooled individuals went virtually unnoticed [9].

In the interim between Cohen, Whitmyre and Funk's study, and the onset of the groupthink dialogue Torrance [10, 11] found increased task persistence, participant perceptions of enjoyment, originality of expression and stimulation in dyads. More tellingly, Torrance [11] also discovered increases in flexibility amongst dyads that foreshadows more recent work on co-inspiration [12].

2.2 Need for Cognitive Closure (NFCC)

Kruglanski's lay epistemics concept of need for cognitive closure (NFCC) is highly relevant to group creativity [13, 14]. NFCC refers to "individuals' desire for a firm answer to a question and an aversion toward ambiguity" [15] and consists of tendencies towards urgency and permanence of cognitive closure [15]. NFCC is both a dispositional trait [16] and a situationally-induced state [15]. Eventual cognitive closure on a subject is necessary, yet prematurely reaching closure undermines the effectiveness of cognitive operations such as formal reasoning [17].

Since 1984 "Resistance to premature closure", or "degree of psychological openness" [18] has been an integral factor in the world's most recognised creativity test—the Torrance Test of Creative Thinking [19, 20].

NFCC is problematic for both individual and group creativity for a range of reasons. Firstly, creative behaviour requires the processing of a variety of information [18, 21], particularly via a search of one's own associative memory [22]. "Closure-bound pursuits" [15] bias the associative memory search choices made [22] and exploratory avenues of thought are ignored. This is particularly detrimental to divergent thinking [23] in non-insight problems [13].

The value of criticism and conflict in group ideation are being increasingly recognised [24–26]. NFCC is detrimental to productive cycles of criticism as it increases the propensity of individuals to reject differing opinions on an issue without consideration [27].

NFCC restricts information processing and the systematicity of information processing is concurrently lowered [28]. Contrary to popular belief, the dogged systematic search of associative memory is conducive to creative productivity [29]. NFCC undermines creative processes by muddling associative memory search functions.

2.3 The Dual Pathway to Creativity Model

The Dual Pathway to Creativity Model [29] posits creative performance as a result of two action paths—cognitive flexibility and cognitive persistence. These distinct paths may intertwine and coincide during the creative process; but one of the two acts as the primary enabler of creative output. The concept of flexibility has been used in creativity research since the field has existed [30, 31]; and the measurement denotes the number of idea categories generated during divergent thinking [10]. Using the flexibility pathway to achieve creative output involves "flexible switching among categories, approaches, and sets, and through the use of remote (rather than close) associations." [29].

The second creativity pathway, persistence, involves "hard work, the systematic and effortful exploration of possibilities, and in-depth exploration of only a few categories or perspectives" [29]. The premise of the persistence pathway is that a concentrated search within a category results in the non-original ideas being used up, and with enough time and effort—more original ideas being produced. This pathway is operationalised by the measure of within category fluency (WCF). This is the average count of how many ideas are produced within each idea category. This is calculated by dividing the total number of ideas generated (fluency) by the number of categories used (flexibility) [29].

The Dual Pathway to Creativity Model views creative output as being contingent upon environmental factors such as approach/avoidance behaviours and group dynamics; and is inclusive towards sociomaterial interactions [32]. In presenting their model, Nijstad et al. postulate that higher working memory capacity—one of

the most universally-recognised benefits of visualisations [33]—is an enabler of the persistence pathway to creativity. The potential of visualisations to delay NFCC and thus hold open the persistence path to creativity is backed by the finding that working memory aids delay NFCC [34].

2.4 Visualisation

Visualisation consists of the "mechanisms by which humans perceive, interpret, use and communicate visual information" [35]. Above and beyond freeing working memory [33], sociomaterial visual practices bring numerous well-recognised benefits to knowledge creation. Visualisation enables the emergence of knowledge creation [36] through the modalities shown below in Table 1.

The factors listed above are of value during dyadic knowledge creation because dyads rely upon visualisations for a "shared interactional space" [44], this is known as the "joint problem-solving space" [45]. The joint problem-solving space is used as the "unfolding setting for the work at hand" [44].

Individual visualisations have a number of discrete dimensions such as visual impact, facilitated insight, and modifiability [46]. Following Gibson's theory of affordances [47], visual representations invite or discourage specific forms of interaction via affordances, which are the perceived opportunities for action an object or environment provides. Each contribution made by an ideator to a joint problem solving space provides an affordance for their partner to accept, question, discard or build upon it. Non-human agents also have a large bearing on the co-creation of knowledge through the mechanism of affordances. Affordances may be designed, but they are also inherent in the properties of visual markings. For example, as shown in Fig. 1—the basic visual element of the line may be more natural or artificial in nature [48]. Natural lines have more variation and this impacts upon people's perception of, and interaction with them—as can be seen in sketches [49]. This study examines the manner in which joint problem-solving space, writing instrument and dyads entangle [50] to create emergent knowledge.

Table 1 Knowledge creation enablers of visualisation

Visual knowledge enabler	Reference
Assistance of remote association triggering	[37]
Common ground creation	[38, 39]
Explicitation of potential connections between elements	[40]
Freeing working memory	[33]
Internal dialogue development	[41]
Inviting reflection	[42]
Provision of overview for creative sensemaking	[43]

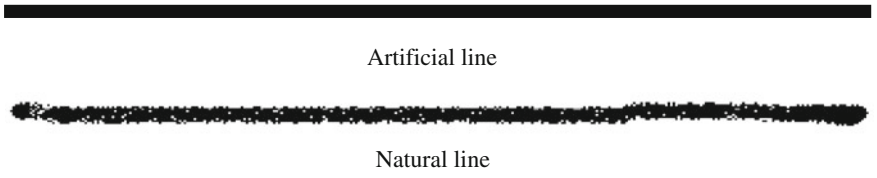

Fig. 1 Artificial and natural lines

Rheinberger [51] makes a telling distinction between technical objects and epistemic objects. An idea visually notated in a dyad's joint problem solving space is a transitory epistemic object, yet they are often misinterpreted as factual technical objects—and fruitful opportunities for knowledge creation are missed. Whyte et al. [52] refer to epistemic objects as being fluid and technical objects as frozen. NFCC results in the fluid being prematurely, and often permanently frozen—whilst ideators move onto completely unrelated ideas. Persistence [29] is effectively the overcoming of NFCC [15]. Overly static visual representations which provide no affordance for persistence potentially exacerbate the freezing and seizing of boundary objects' fluidity.

In the current context, visualisations are generated by a combination of human agents, inscription and display devices. A writing instrument such as a pen is an example of an inscription device, while a sheet of paper is exemplary of a simple display device. This study's operationalisation of inscription and display devices is fully listed in Table 2, and shown in Fig. 3. Despite an increasing recognition of the importance of sociomaterial processes and objects [53] both inscriptive and display non-human agents [54] of notation, or notation materials, have gone unexamined in the realm of group creativity. In examining notation materials and their interactions, this pilot study begins to remedy this deficit.

Raw artefacts in the midst of creation by ad hoc groups are relatively low in structure, and high in subjectivity and embeddedness within a group context [55]. Therefore, they are fundamentally epistemic [51], or fluid [52]. This study examines whether consistently fluid notation materials will support emergent sociomaterial objects' development more effectively than the contradictory use of frozen notation

Table 2 Operationalisation of fluid and frozen inscription and display devices

Concept	Operationalisation
Fluid inscriptive non-human agent of notation	Pencil with eraser
Frozen inscriptive non-human agent of notation	Pen
Fluid display non-human agent of notation	Blank A3 sheet of paper
Frozen display non-human agent of notation	A3 sheet of paper with pre-printed mind map template

materials. Complementary sociomateriality in-sync with the group's function is predicted to facilitate persistent creativity [29] in the face of NFCC [15].

Seeber et al. [55] introduce the idea trace phases of controversial initiation, supportive enrichment, steadfast challenge and committed integration. The concept of idea trace phases can also be applied to idea category. Each idea which steps away from the category undergoing supportive enrichment and opens up a new idea category represents at least temporary cognitive closure on the extant category, and the beginning of a new phase of controversial initiation. Through impacting upon NFCC on idea category via degree of fluidity [52], differing compositions of notation materials will affect the level of enrichment, challenge and perceived integration of an idea category's ideas. The perceived modifiability of sociomaterial emergences impacts upon the affordance they create.

2.5 *Hypothesis Development*

The various actors in the entanglement of writing instrument, display device and dyad are envisaged to create replicable patterns of interaction. Bearing the literature on dyads, NFCC, the Dual Pathway to Creativity Model [29] and visualisation in mind, a hypothesis on the relationship between writing instrument and display device, and their impact upon creativity in a dyadic mind mapping context will be developed below. Figure 2 depicts a conceptual model in which display non-human agent of notation, or display device, is conceptualised to operate via affordance effects [47]. Frozen pre-existing visual templates with vacant affordances for new ideas and idea categories pre-validate any new category initiation. There can be no controversy [55] in satisfying an affordance. In the case of pre-existing mind map templates, individuals sate templates' affordances to supply idea categories to 'empty branches'.

In contrast, when groups create their own mind maps, there are no empty branches. New branches are only created and the first idea noted after a new idea

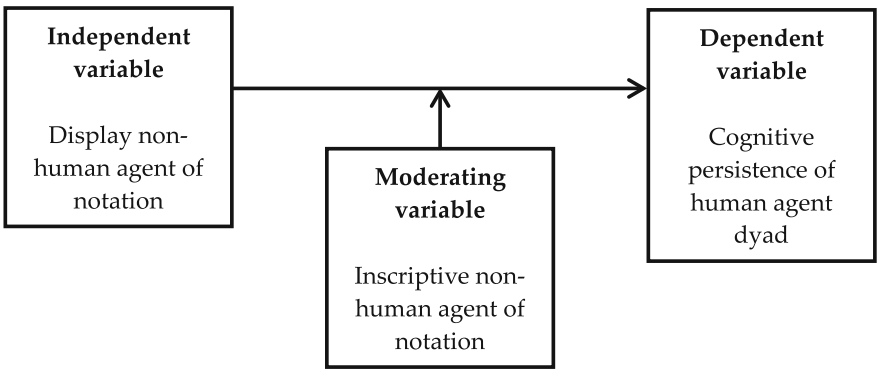

Fig. 2 Conceptual model

category has been cognitively opened by at least one individual. The affordance for individuals then becomes the population of the newly created branch at hand. Prior to a new idea category passing through initial cognition and controversial initiation [55], no empty branch graphically exists to invite supportive enrichment [55]. Once a new idea category branch has been graphically depicted and cognitively opened on a mind map, closely-related, within category ideas will be contributed until within category persistence flags [29], and a new category is opened. Within a highly modifiable joint problem solving space, the cognitive opening and public notation of a new idea category is capitulation to NFCC on idea category and the abandonment of a joint cognitive effort to flesh out the invitation of an at-hand idea category. Display devices operate according to principles of affordance, and their emergent sociomateriality interacts with other agents to develop varying levels of cognitive persistence despite NFCC [15].

Inscriptive non-human agents of notation, or writing instruments, are a fundamental component of emergent sociomaterial processes and objects. Interactions between human agents and writing instruments will impart differing degrees of fluidity [52] upon sociomaterial objects. Fluidity itself is an affordance.

A set of ideas consists of categories [30]. The emergence of idea categories is a result of "structured imagination" [56]. During the attribution of an idea to a category, human agents' "imagination is structured by a particular set of properties that are characteristic of that category" [56]. Central aspects of idea categories derived from naïve mental models [57] define an individual's categories, and multiple human agents subsequently use naïve mental models [58] to compare any new ideas to a prototypical category member's central attributes in order and determine the new item's category membership.

The acceptance of wider deviation from an idea category's central attributes' increases the inclusivity of an idea category. The relatively naturalistic markings of fluid writing instruments are more loosely interpreted than those of comparatively artificial frozen writing instruments [46]. Graphite markings thus lend themselves to the creation of less fine-grained categories than ink markings. Writing instrument markings communicate provisional category norms, which human agents perceive as flexible. Inclusivity of category is expected to result in more persistence [29].

Following the reasoning above, it is hypothesised that fluid non-human display agents of notation and fluid inscriptive non-human agents of notation will interact resulting in the emergence of higher levels of persistence in human agent dyads [29] than is displayed by dyads equipped with frozen non-human display agents of notation and frozen inscriptive non-human agents of notation. In other words, it is predicted that synergies between fluid display devices and fluid writing instruments will enable more persistence in pairs than frozen display devices and frozen writing instruments. This relationship is depicted in Fig. 2.

3 Method

3.1 Research Design

A 2 × 2 factorial experiment was selected to test the hypothesis. The independent variables are instrument and worksheet used by the dyads, and the dependent variable is within category fluency. The fluidity of display non-human agents of notation was operationalised by blank sheets of A3 paper (fluid) and A3 sheets with a pre-printed mind map template (frozen). The fluidity of inscriptive non-human agents of notation was operationalised by pencils with eraser (fluid) and black pens (frozen). By inherent nature of their markings, pen ink produces relatively artificial lines whilst pencil graphite produces comparably natural lines [48]—therefore pens were used to operationalise frozen rigidity and pencils were used for the operationalization of fluidity. The exact materials used are listed in Table 2 and depicted in Fig. 3.

The ideation task was "develop ideas for inexpensive giveaways to remind and inspire employees organisation-wide of a new strategy". This task was chosen because of its universal accessibility, and applicability to participants. It is also in line with Ward's experimental tasks [56].

3.2 Participants

All 58 participants were middle or upper managers from central Europe with at least 10 years of professional experience in departments such as IT, engineering, and

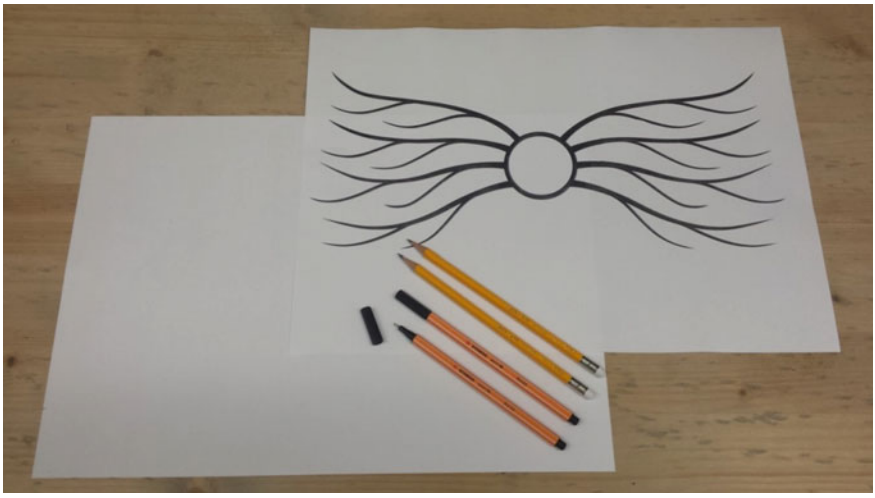

Fig. 3 Worksheets and materials provided

marketing. The participants were from 55 different organisations. Participants' industries were: construction (5.1 %), consulting (6.8 %), education (1.7 %), engineering (6.8 %), financial services (20.2 %), fast moving consumer goods (3.4 %), healthcare (13.6 %), ICT (11.9 %), manufacturing (10.2 %), NGO (1.7 %) and the public sector (18.6 %). Participants had only superficial previous knowledge of each other. The sample was comprised of 79 % males and 21 % females.

3.3 Procedure

The experiment was twice repeated during two separate executive MBA courses on strategic management. The procedure and time of day was identical in both iterations. Participants were told that they would be assigned to dyads, required to generate ideas for a soon-to-be-assigned task using a mind map [59]; and finally select and summarise their best idea [60] using a standardised sheet. Radial mind maps were chosen for their ubiquity [61] and accessibility [40]. To ensure uniform knowledge, mind map use for ideation was briefly explained [62]. Dyads were then randomly formed by the experimenters, and materials assigned to them. Finally, participants were told that there was no minimum or maximum time limit for the simulation, and the ideation task was publicly announced and visibly noted. Upon finishing the activity, participant pairs handed in their mind maps, best idea summary sheet and writing instruments. The time of submission was noted, and participants were each given a short survey to measure control variables.

4 Results

At the outset of the experiment, two participant pairs left the experimental environment, and completed the task at external tables. Their results were removed from analysis.

Mind maps were examined as representative of each group's creative process. Fluency and flexibility require measuring to attain the persistence measurement of WCF. The first measurement taken from all mind maps was ideational fluency [25].

Flexibility was next measured following the work of Seeber et al. [55]. Category coding was begun, and a list of coded idea categories of uniform granularity gradually emerged—for example office stationary, games, and toys. If an idea did not fit into a previously created category, then an appropriate new category was created and added to the category list.

WCF was subsequently calculated using the fluency and flexibility values. The results are reported in Table 3. Neither fluency nor flexibility were significantly different as main factors. The control variables measured by survey had no effect on the result.

Table 3 Factor means

	Condition							
	Blank worksheet with pencil (n = 12)		Blank worksheet with pen (n = 16)		Template worksheet with pencil (n = 12)		Template worksheet with pen (n = 14)	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Fluency	26	20	17	12	17	12	13	5
Flexibility	8	8	6	3	6	2	4	1
Within category fluency (WCF)	3.79	1.73	2.67	1.13	2.46	1.28	3.04	0.92

n = 54

Fluency, flexibility and WCF differences between the two operational fluidity factors were next examined using one-way ANOVA. The results are presented below in Table 4.

As can be seen, main factor alone played a non-significant role on the fluency, flexibility or WCF of creative output. Univariate analysis of variance was then used to test for moderation of writing instrument fluidity upon display device fluidity. The results are shown below in Table 5.

Univariate analysis of variance shows that the interaction between worksheet and writing instrument for WCF is significant at a level of $p = 0.013$. The univariate analysis of variance general linear model in Fig. 4 shows the powerful crossover interaction between worksheet and writing instrument impacting upon WCF.

Table 4 Factor one way ANOVAs

	Factor							
	Worksheet (n = 54)				Writing instrument (n = 54)			
	ANOVA: Between groups				ANOVA: Between groups			
	df	Total df	F	Sig.	df	Total df	F	Sig.
Fluency	1	53	2.729	0.105	1	53	2.685	0.107
Flexibility	1	53	2.125	0.151	1	53	2.542	0.117
Within category fluency (WCF)	1	53	0.727	0.398	1	53	0.383	0.539

n = 54

Table 5 Univariate analysis of variance moderation test

Source	df	F	Sig.
Worksheet	1	1.419	0.239
Writing instrument	1	0.365	0.549
Worksheet * Writing instrument	1	6.653	0.013

a. R Squared = 0.137 (Adjusted R Squared = 0.085)
b. Computed using alpha = 0.05
n = 54

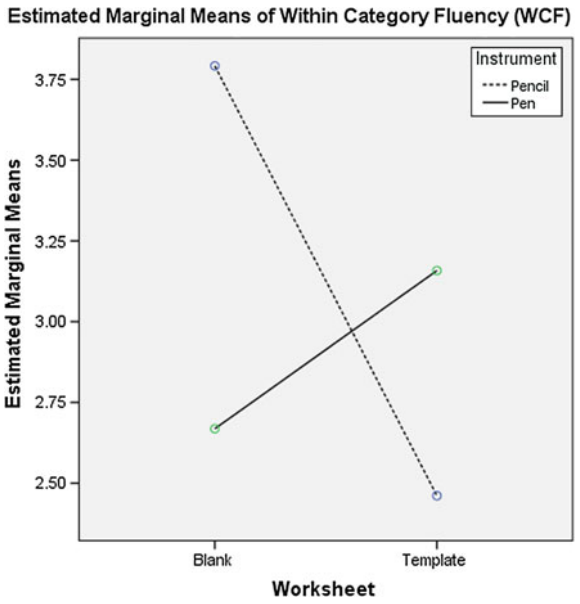

Fig. 4 Moderating effect of worksheet and instrument for within category fluency (WCF)

As seen in Fig. 4, idea generating dyads using pencils with a blank page were approximately twice as persistent as dyads using pencils with a mind map template. A much slighter increase in WCF emerged from idea generating dyads using pens with a mind map template in comparison with pairs using pens and a blank page.

It should finally be noted that although erasers were provided on the end of every pencil in the relevant conditions, none were used.

5 Discussion

The hypothesis that interaction between fluid display devices and fluid writing instruments encourages the emergence of persistence in dyads [29] was supported. As hypothesised, writing instruments' fluidity moderates worksheet fluidity resulting in higher cognitive persistence within dyads. This effect is examined in more detail below.

When the affordance of pre-supplied mind maps to create new idea categories is not present, the cognitive persistence of dyads using fluid, relatively naturalistic markings is increased due to widened category inclusivity. In contrast, when pre-printed mind map branches with multiple contribution affordances are not made available to dyads using the frozen, comparably artificial medium of pen, dyads merely open and close idea categories superficially [48]. These dyads indulged in the claiming of cognitive categories. Frozen ink markings impart very little leeway from central idea category-defining attributes [56] when used freely. To paraphrase

Ward [56], ink rigidly structures imagination and the result is NFCC on idea category.

The strength of affordances is evident in both writing instrument operationalisations. As seen in Fig. 3, each branch of the pre-supplied mind map templates had three affordances for within category ideas. The mean WCF in the template with pen condition was 3.04 (s.d. 0.91). The close mapping between the template affordances and results produced reveal the tempering of ink's rigid category centrality [56] of ink by mind map affordances.

Most notably, the influence of pre-supplied templates decimated the inclusive category leeway [56] of graphite markings. The cognitive persistence of dyads freely creating emergent sociomaterial objects with fluid, somewhat naturalistic markings is shown to be delicate and easily disrupted by the rigidity of pre-supplied templates. In such cases, these templates actually induce NFCC through the affordance to create new idea categories. Graphite markings allow the loose structuring of imagination, yet the very fragility of its framing,which allows for inclusive deviations from central category attributes [56], is easily disrupted by fixed visual template affordances.

6 Conclusion

This study is not without its limitations. This pilot study used a relatively small sample from a limited cultural range, under laboratory conditions. Coding was carried out by a single independent researcher. The current study used only two operationalisations each of display device and writing instrument. Future studies would address these shortcomings and widen the variety of operationalisations, with the aim to include digital variants. Future data collection would include qualitative data to be used in an integrative mixed methods approach [63].

This pilot study opens numerous avenues for further research. More research into the moderation of visual working space effects by notation instrument is called for.

One factor uncovered by this pilot study particularly merits further study: the absence of externally-supplied affordances is not the absence of affordances. Groups with blank worksheets were generating their own affordances as their mind maps emerged. An exploration of differences between personally-generated and externally-supplied affordances would be a useful contribution to affordance theory.

In summary, this pilot study has found the category inclusivity effect of writing instrument to moderate the affordance effect of display devices on idea generating dyads' cognitive persistence [29]. Emergent sociomaterial interactions have thus been shown to be capable of lessening the impact of NFCC in knowledge creation [1]. The fluidity of visualisation components acts as cognitive antifreeze upon NFCC in idea generating dyads.

This study has found the gap-filling affordance of static pre-structured templates to negatively impact the creative persistence [29] enabled by the category

malleability effect of fluid, naturalistic markings. However, digital environments are dynamic, and the evident effects of affordances could be dynamically employed to foster creative contributions. For example, mind-mapping software could relatively easily detect the filling of main, category level mind map branches, and create empty new category branches to afford more contributions. At a simple level, mind-mapping software could operate via a programmed rule to automatically add a new sub-branch extending from every single new contribution to a mind map. These vacant sub-branches would de-centrally elicit knowledge. A more sophisticated phased treatment is also technically possible—a model of phased affordances could encourage participants to push themselves to gradually build up and connect layered categories of knowledge in the shared visual working space. A phased model of dynamic—not static, pre-structured—affordances in combination with natural, graphite lines [48] would invite creativity via participants' deep, systematic search of associative memory [29, 64] and idea combination [65].

In general, software design for idea generation, including social media platforms for innovation, should take note of the malleable category inclusivity effect of natural, graphite lines [48] and mimic these. A further application of the finding that natural graphite markings have an advantageous yet delicate function as cognitive antifreeze in the absence of pre-existing structures is in tablet computers' handwriting recognition systems. Handwriting recognition software designed for the support of divergent thought [23] should encourage the retention of user-produced natural lines, instead of transforming users' natural lines into artificial lines by default. Furthermore, automated processes for ordering users' knowledge structures into templates such as stakeholder maps should respect users' existing natural lines as much as possible and produce user line/template hybrids.

Social media platforms for innovation have, at times, suffered under low quality of discussion. The duplicate addition of identical ideas contributes to this problem [66]. The fluid presentation of previously-supplied ideas to potential idea providers could lead to within-category expansion upon them and bolster the idea pool.

The findings of this study are also useful for knowledge managers who can use them to compose sociomateriality in order to elicit or rescind cognitive persistence in dyads in a range of situations. For example, knowledge managers can use the space/medium sociomaterial interaction described as a powerful tool by which to allay the deleterious effects of NFCC on creative output [14]. This sociomaterial effect is especially useful in solving problems prone to eliciting false insights [67] when persistence is needed to push past seemingly satisfactory initial solutions in order to tap into truly creative veins of cognition. Such scenarios can be found in a range of problems from the introduction of new technology into an organisation to resolving thorny programming challenges. Sociomateriality has been shown to matter to the search for creative solutions.

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