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Cross-Domain Influences on Creative Innovation: Preliminary Investigations

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Abstract

This paper takes a two-pronged approach to investigate cross-domain influence on creativity. We present a study in which creative individuals were asked to list influences on their creative work. More than half the listed influences were unrelated to their creative domain, thus demonstrating empirically that cross-domain influence is widespread. We then present a preliminary model of exaptation, a form of cross-domain influence on creativity in which a different context suggests a new use for an existing item, using as an example waste recycling of petroleum byproducts.

Keywords: art, concepts; context; creative writing, cross-domain, cross-modal; creativity; exaptation; influence; innovation; music, quantum cognition; sustainability

Introduction

The study of cross-domain thinking in cognitive science has focused largely on analogy and metaphor, but the phenonmenon extends further and plays a role in the generation of artistic masterpieces and technological feats. One indication of this is a tradition in the arts, referred to as *ekphrastic expression,* of interpreting art from one medium (*e.g*., acrylic painting) into another (*e.g*., charcoal sketch). The goal of ekphrastic expression is to capture, and thereby become intimate with, the underlying form or essence of a work by translating it from one medium into another, and thereby have a more direct impact on an audience. A related phenomenon is *cross-media style*, wherein the same style is demonstrated by works in different media; for example, the term rococo is given to a style of painting, sculpture, literature, and music of the 18th Century. It is thought that works in a particular style suggest underlying abstract archetypal forms to the artistic mind that compel the exploration of different manifestations (Burke, 1957).

The phenomena of ekphrastic expression and cross-media style are consistent with evidence that creative works in different media may be similar in terms of psychophysical, collative, and ecological properties (Hasenfus, 1978). Aesthetic perceptions stimulated by creative works may generate physiological, emotional, cognitive, and/or behavioral, responses that are amenable to re-expression in other forms. This may be due to regularities in the choice of elements (*e.g.*, shapes, colors, or words) and/or how they are used (*e.g*., in a chaotic or orderly manner) (Berlyne, 1971). It has been shown that there are non-arbitrary mapping between properties of vision and sound (Griscom & Palmer, 2012; Melara, 1989; Melara, & Mark, 1990; Palmer, Schloss, Xu, & Prado-Leon, 2013; Ward, Huckstep, & Tsakanikos, 2006). For example, the processing of visual features, such as lightness and spatial frequency, can be affected by auditory features such as pitch and timbre (Marks, 1974, 1975, 1987).

In a study of cross-domain creativity that aimed to move beyond single-dimensional mappings, composers were asked to write music inspired by four simple line-drawn shapes: a square, a lightning bold, a curvy shape, and a jagged shape (Willmann, 1944). Music inspired by the same shape was more similar than music inspired by another shape with respect to tempo, melodic pattern, mood, and other characteristics, and listeners could match above chance the music to the shape that inspired it. However, the impoverished nature of the stimuli undoubtedly limited the scope for creative expression. Another study aimed at investigating whether the rich emotionality of genuinely creative works could be translated to, and recognized in, in another domain. It demonstrated that when pieces of music were re-interpreted as paintings, naïve participants were able to correctly identify at significantly above chance which piece of music inspired which painting (Ranjan, Gabora, & O'Connor, 2014; Ranjan, 2014). Although the medium of expression is different, something of its essence remains sufficiently intact for an observer to detect a resemblance between the new work and the source that inspired it. This result lent empirical support to the largely anecdotal evidence that cross-domain influence is a genuine phenomenon, and suggested that, at their core, creative ideas are less domain-dependent than they are generally assumed to be. It did not, however, provide evidence that the phenomenon extends beyond the artificial conditions of such a study, nor did it indicate how prevalent it is.

A Study of Cross-Domain Influence on Creative Innovation

The goal of the present study was to provide a preliminary assessment of the extent to which creative individuals are influenced by stimuli and experiences that are either directly related, indirectly related, or unrelated to their domain of creative expression.

Method

Participants were recruited by conducting an internet search to locate 150 individuals who have made a significant contribution in a creative domain. They were invited by email to participate in the study on a voluntary basis. The email provided a link to a questionnaire that was hosted by SurveyMonkey. There was no remuneration for participation. The questionnaire asked their gender, age, and occupation, as well as the following questions:

1. What is the general category for the creative work for which you are most known (e.g., art, music, drama, science)?
2. What is the subcategory for the creative work for which you are most known (e.g., painting, piano composition, biochemistry)?
3. Please describe your creative outputs.
4. Please describe as best you can your creative process.
5. Describe all elements that have inspired your work (natural or artificial, or it may be a particular event or situation, or something not in the concrete environment, that is, something abstract that you have been thinking about), and with each item, if possible, put as much identifying information as you can about the item it inspired (e.g., my Sunlight Sonata in B Flat composed in 2012 was inspired by going skiing in the alps with my sister who had just recovered from pneumonia). Do this for as many of your creative works as you can.

The first three questions were used to categorize the creators into the following primary creative domains: art, music, and writing. Artists were further categorized into secondary domains: painting, drawing, photography, and sculpture. Question four was not used in this analysis. Responses to question five were divided into four categories: cross-domain, within-domain narrow, within-domain broad, and uncertain. The first three categories were created based on prior research. The influence was classified as *cross-domain* if it was unrelated to its creative domain. It was classified as *within-domain narrow* if it was clearly related to its creative domain. The *within-domain broad* category was used when not enough information was provided to distinguish between within- and cross-domain.

Results

Of the 150 emails sent out, 80 people responded (53.3% response rate). 14 participants had incomplete information so were not included in the analysis. The remaining 66 participants provided 65 influences. Examples of each category of influence are provided in Table 1. The total number of influences in each category is given in Table 2. The frequency of cross-domain influences (47%) was greater than that of within-domain influences (27%), and this was the case even when broad as well as narrowly construed within-domain influences were considered (35%).

Table 1: Examples from the data of each of the four categories of influence. Top: narrow within-domain (WD-n) and broad within-domain (WD-b) influences. Bottom: cross-domain influences (CD) and influences categorized as “uncertain” (U). A dash indicates that no examples of that category were present in the data.

Creator	**WD-n**	**WD-b**
Artist - Painting	Galleries	Spirograph
Artist - Drawing	Political cartoonists	–
Artist - Photography	–	Books and lectures on subject of “understanding pictures”
Artist -Sculpture	–	Architectural elements
Musician	Band musician collaboration	–
Writer	Conferences	–

Creator	**CD**	**U**
Artist - Painting	Global warming	Opposites
Artist - Drawing	Comedy	Circular intellect
Artist - Photography	Meditation	–
Artist -Sculpture	Computer programming	World
Musician	Literature	Creativity seminar
Writer	Nature	Retreats

Table 2: Number of participants in each creative domain (N), and the raw number (r) and percentage (%) of influences that were cross-domain (CD), within-domain: narrow (WD-n), within-domain: broad (WD-b, and uncertain (U). Percentages are in brackets.

Creative	N	CD		WD-n		WD-b		U	
Domain		r	(%)	r	(%)	r	(%)	r	(%)
Painting	44	21	(48)	12	(27)	4	(9)	6	(14)
Drawing	8	2	(25)	2	(25)	–	–	3	(38)
Photography	4	2	(50)	–	–	1	(25)	–	–
Sculpture	5	3	(60)	–	–	–	–	1	(20)
Music	3	1	(33)	2	(68)	–	–	1	(33)
Writing	2	2	(100)	1	(50)	–	–	1	(50)
TOTAL	66	31	**(47)**	17	**(27)**	5	**(8)**	12	**(18)**

Discussion

These results demonstrate that even if individuals primarily express their creativity in a single domain, they are often employing cross-domain thinking when they create. The study enriches our understanding of how the creative process works by adding to a growing body of evidence that creativity is not just a matter of acquiring domain-specific expertise. A limitation of the study is that it focused exclusively on artistic creativity. In further investigations along these lines we will attempt to obtain data on individuals who are scientifically and technically creative.

A Quantum Model of Cross-Domain Influence on Creative Innovation

An interesting form of cross-domain influence is *exaptation,* wherein a trait that originally came about to solve one problem is co-opted for another use. The concept of exaptation comes from biology but has been shown to play a pivotal role in economics (Dew, Sarasvathy, & Ventakaraman, 2004). A preliminary attempt has been made to develop a mathematical model of exaptation that can be applied across disciplines (Gabora, Scott, & Kauffman, 2013). Here we use it to model cross-domain influence on creative innovation. Waste recycling is a particularly interesting form of cross-domain influence on innovation because of its applications to sustainability efforts. An item that is a wasteful byproduct in one context is found to be useful in a different context.

The model we use is a generalization of the formalism of quantum mechanics adapted for application in a psychological context (Aerts & Gabora, 2005; Aerts, Gabora, & Sozzo, 2013; Busemeyer & Bruza, 2012; Pothos & Busemeyer, 2013).[1] Quantum probability models in psychology have been compared side-by-side with classical models (Busemeyer, Pothos, Franco, & Trueblood, 2011). According to classic probability, all events are subsets of a common sample space; that is, they are based on a common set of elementary events. An important advantage of a quantum model over a classical model such as a Bayesian one is that it uses variables and spaces that are defined specifically with respect to a particular context, which is necessary to capture certain aspects of how concepts behave (Aerts & Gabora, 2005; Gabora & Aerts, 2002; Kitto, Ramm, Sitbon, & Bruza, 2011). The state $|\psi\rangle$ of an entity is written as a linear superposition of a set of basis states $\{|\phi_i\rangle\}$ of a Hilbert space $\mathcal{H}$, which is a complex vector space with an inner product.[2] Another advantage of a quantum model over a classical one is that it uses *amplitudes*, which though directly related to probabilities, can exhibit interference, superposition, and entanglement, which are also needed to capture certain aspects of how concepts behave (Aerts, 2009; Aerts, Broekaert, Gabora, & Veloz, 2012; Aerts et al., 2013; Aerts & Sozzo, 2011; Bruza, Kitto, Ramm, & Sitbon, 2011). The amplitude term, denoted a_i, is a complex number that represents the contribution of a component state $|\phi_i\rangle$ to the state $|\psi\rangle$. Hence $|\psi\rangle = \Sigma_i a_i |\phi_i\rangle$. The square of the absolute value of the amplitude equals the probability that the state changes to that particular component basis state. A change of state is called a *collapse*. The choice of basis states is determined by the observable O to be measured, and its possible outcomes o_i. The basis states corresponding to an observable are referred to as *eigenstates*. Observables are represented by self-adjoint operators on the Hilbert space. The lowest energy state is referred to as the ground state. Upon measurement, the state of the entity collapses from its current state (possibly the ground state) and is projected onto one of the eigenstates.

Now consider two entities A and B with Hilbert spaces $\mathcal{H}_A$ and $\mathcal{H}_B$. We denote amplitudes associated with the first and second as a_i and b_j respectively. The Hilbert space of the composite of these entities is given by the tensor product $\mathcal{H}_A \otimes \mathcal{H}_B$. We may define a basis $|e\rangle_i$ for $\mathcal{H}_A$ and a basis $|f\rangle_j$ for $\mathcal{H}_B$. The most general state in $\mathcal{H}_A \otimes \mathcal{H}_B$ has the form

$$|\psi\rangle_{AB} = \Sigma_{i,j}\, c_{ij}\, |e\rangle_i \otimes |f\rangle_j \quad (1)$$

where c_{ij} is the amplitude corresponding to the composite entity.

The phenomenon of *entanglement* was conceived to deal with situations of non-separability where different entities form a composite entity. The state $|\psi\rangle_{AB}$ is separable if for the amplitudes c_{ij} amplitudes a_i and b_j can be found such that $c_{ij} = a_i\, b_j$. It is inseparable, and therefore an entangled state, if this is not possible, hence if the amplitudes describing the state of the composite entity are not of a product form.[3] Entangled states are non-compositional because they may exhibit emergent properties not inherited from their constituent components.

The quantum formalism is not general enough to model all concept combinations but generalizations of it have been developed that are quantum-like. In quantum inspired models of concepts, a context plays the role of a measurement. A set of basis states related to a context represents instances of a concept. A context can exert either a deterministic or probabilistic influence on the state of a concept. If there is no uncertainty or choice involved then the change of state is deterministic and this is represented by a linear operator, which may be a unitary operator, a projection operator, or an operator of a more general nature,

[1] This approach is unrelated to quantum models of consciousness (Hammeroff, 1998) or memory (Pribram, 1993), and makes no assumption that phenomena at the quantum level affect the brain; it draws solely on abstract formal structures that, as it happens, found their first application in quantum mechanics.

[2] It is slightly more complex but more accurate to define a Hilbert space as a real or complex inner product space that is also a complete metric space with respect to the distance function induced by the inner product. The inner product allows one to define the length of a vector and the angle between two vectors, as well as orthogonality between vectors (zero inner product).

[3] In some applications the procedure for describing entanglement is more complicated than what is described here. For example, it has been argued that quantum field theory, which uses Fock space to describe multiple entities, gives an internal structure that is superior to the tensor product for modeling concept combination (Aerts, 2009). Fock space is the direct sum of tensor products of Hilbert spaces, so it is also a Hilbert space.

depending on the type of contextual influence. If there is uncertainty or choice involved then the change of state is probabilistic. Different possible outcomes can occur, each with a certain probability, and the effect of context is represented by a self-adjoint operator.

In one generalized quantum formalism, namely the State Context Property (SCOP) theory of concepts, a concept is defined in terms of (1) its set of states Σ (including both exemplars and ground states changed under the influence of a context), a set $\mathcal{L}$ of relevant properties, (3) a set $\mathcal{M}$ of contexts in which the concept may be relevant, (4) a function ν that gives the applicability or *weight* of a certain property for a particular state and context, and (5) a function μ that gives the probability of transition from one state to another under the influence of a particular context. We might represent the state of a chair by a vector $|p\rangle$ of length equal to 1 in a complex Hilbert space $\mathcal{H}$. From a different context this state $|p\rangle$ could actualize as another state. For example, in the context office it may actualize as the state OFFICE CHAIR, while in the context kitchen it may actualize as the state KITCHEN CHAIR. These are deterministic changes of state.

More interesting is a probabilistic change of state in which there are two or more possible outcomes. For example, consider the reconceptualization of what to do with excess petroleum byproducts post World War II. The concept PETROLEUM BYPRODUCTS in peoples' minds could change probabilistically from $|p\rangle$ to one of two states: $|u\rangle$, the state in which it is viewed as *useful* (*e.g.*, they invent a new use for it), and $|w\rangle$, the state in which it is viewed as *waste*. The state of PETROLEUM BYPRODUCTS prior to being conceived of as useful or waste is modeled as a superposition of these two possibilities. The vectors $|u\rangle$ and $|w\rangle$ form the basis of a complex Hilbert space. Thus state $|p\rangle$ of PETROLEUM BYPRODUCTS can be written as a superposition of $|u\rangle$ and $|w\rangle$, *i.e.*,

$$|p\rangle = a_0|u\rangle + a_1|w\rangle \qquad (2)$$

where a_0 and a_1 are complex numbers that give the amplitudes of $|u\rangle$ and $|w\rangle$ respectively. More concretely, the probability that $|p\rangle$ is viewed as useful equals $|a_0|^2$, the square of the absolute value of a_0. The probability it is viewed as waste equals $|a_1|^2$, the square of the absolute value of a_1. If it were to be decided that PETROLEUM BYPRODUCTS are useful or waste the state would change probabilistically from $|p\rangle$ to $|u\rangle$ or $|w\rangle$. The states $|u\rangle$ and $|w\rangle$ are thus eigenstates of PETROLEUM BYPRODUCTS in a default, generic context. In different individuals a_0 and a_1 may have different values (as epitomized in the saying, "one person's trash is another person's treasure"). PETROLEUM BYPRODUCTS may also be conceived differently by the same person in different modes of thought. Divergent thinking may facilitate the process of viewing PETROLEUM BYPRODUCTS in a new context, such as converting them into useful plastic objects, which changes the likelihood of them being viewed as useful or waste. Activation of the set $\mathcal{L}$ of properties of plastic—which includes for example 'moldable' and 'unbreakable', denoted f_1 and f_2 respectively—causes activation of other concepts for which these properties are relevant. Contexts for which some of these properties are relevant become candidate members of the set $\mathcal{M}$ of relevant contexts. One such context is the making of kitchenware and utensils, denoted kitchen.

Recall that states are represented by unit vectors, and all vectors of a decomposition such as $|u\rangle$ and $|w\rangle$ have unit length, are mutually orthogonal, and generate the whole vector space; thus $|a_0|^2 + |a_1|^2 = 1$. This means that the change in the probability that petroleum byproducts are viewed as useful if one considers them from a different context can be modeled using a Pythagorean argument, as in Figure 1.

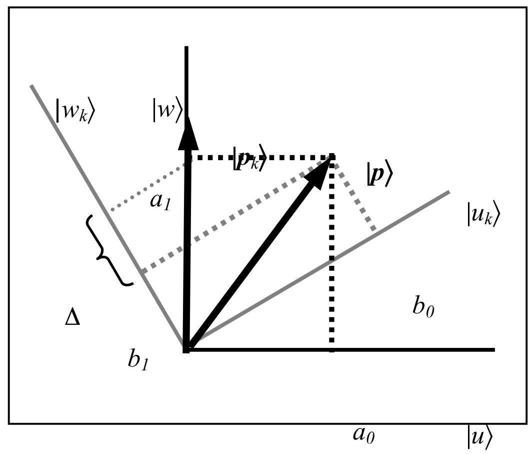

Figure 4: Graphical depiction of a vector $|p\rangle$ representing the state of PETROLEUM BYPRODUCTS. In the default context it is likely to collapse to the default projection vector $|w\rangle$ which represents that it is waste. This can be seen by the fact that subspace a_0 is smaller than subspace a_1. Thinking more creatively one might consider turning about petroleum byproducts into useful plastic objects such as unbreakable dishes. Thus in the context of kitchen (shown in gray), the state of PETROLEUM BYPRODUCTS is likely to collapse to the orthogonal projection vector $|u\rangle$ which represents that it is useful, as shown by the fact that b_0 is larger than b_1. Also shown is the projection vector after renormalization (the vertical arrow).

Given the context kitchen, denoted k, some creative states of PETROLEUM BYPRODUCTS are to use it to make plastic *cookware* (e.g., pots or casserole dishes) or *dishware* (e.g., plates and bowls). Let us show that the formalism is capable of incorporating these states. This will not be possible in the Hilbert space formed by the two states $|u\rangle$ and $|w\rangle$ because it has only two dimensions. The restructured conception of PETROLEUM BYPRODUCTS in the context kitchen, denoted $|p_k\rangle$, is given by

$$|p_k\rangle = a_3 \mathrm{P}u_k\, |p_k\rangle / \|\, \mathrm{P}u_k\, |p_k\rangle \| + a_4|w_k\rangle \qquad (3)$$

where Pu_k is an orthogonal projection operator. We substitute in the mathematical formalism of Hilbert space for the unit vector whenever what physicists call 'degeneration' is involved, meaning that several orthogonal states can give rise to the same property, here the property *useful.* Note that $||Pu_k |p_k\rangle||$ is the length of $Pu_k |p_k\rangle$. We need to divide the vector $Pu_k |p_k\rangle$ by $||Pu_k |p_k\rangle||$ for it to become a unit vector, and hence represent a state. Let us specify these states of usefulness to make the mathematical description complete. Since we want to consider creative useful states, specifically COOKWARE and DISHWARE, we introduce the states $|c\rangle$ and $|d\rangle$ respectively. In the context kitchen they are denoted $|c_k\rangle$ and $|d_k\rangle$. $|b_k\rangle$ denotes the possibility that even in the context kitchen petroleum byproducts are viewed as useful just as they are (however unlikely this may be), and $|b_kc_k\rangle$ and $|b_kd_k\rangle$ denote the possibility that in this context petroleum byproducts are turned into plastic to make cookware and dishes, respectively. We write the projector as the sum of the partial projectors on the states. Hence we have

$$Pu_g = |b_k\rangle\langle b_k| + |b_k c_k\rangle\langle b_k c_k| + |b_k d_k\rangle\langle b_k d_k| \quad (4)$$

where $|b_k\rangle\langle b_k|$, $|b_k c_k\rangle\langle b_k c_k|$ and $|b_k ds_k\rangle\langle b_k d_k|$ are the one dimensional orthogonal projection operators on the vectors $|b_k\rangle$, $|b_k c_k\rangle$ and $|b_k d_k\rangle$ respectively. By considering petroleum byproducts in different contexts, the perceived probability that they are useful has increased, *i.e.*, $|a_3|^2 > |a_0|^2$ because the state $Pu_k |p_k\rangle/|| Pu_k |p_k\rangle||$ incorporates possibilities of being used as cookware or dishware.

The set of properties of COOKWARE includes 'temperature resistant' because it is placed in or on a stove. This property is denoted f_3. Since plastic can burn, it is not temperature resistant, so $\nu(p, f_3) << \nu(c, f_3)$. Writing the unit vector $Pu_k |p_k\rangle/|| Pu_k |p_k\rangle||$ again as a superposition of vectors $|b_k\rangle$, $|b_k c_k\rangle$ and $|l_k d_k\rangle$ we have:

$$Pu_k |p_k\rangle/|| Pu_k |p_k\rangle|| = a_5|b_k\rangle + a_6|b_k c_k\rangle + a_7|b_k d_k\rangle \quad (5)$$

Because plastic can burn, $|a_6|^2$ is small. However, plastic would be particularly useful for making children's dishes because it has the property f_2 of not breaking easily, so $\nu(p, f_2) \approx \nu(d, f_2)$. Therefore, $|a_7|^2$ is large, and $\mu(d, k, p) >> \mu(c, k, p)$. Thus in the context kitchen, the concept PETROLEUM BYPRODUCTS has a high probability of collapsing to PLASTIC DISHWARE.

We can model the emergence of new properties using the notion of entanglement. Although the state PLASTIC DISHES was modeled by $p_k d_k\rangle$ as one of the sub-states of PETROLEUM BYPRODUCTS, the quantum formalism can also be used to derive this state as a combined state of PETROLEUM BYPRODUCTS and DISHWARE. It has been shown experimentally that such a combined state is in general not a product state but an entangled state (Aerts et al., 2013; Aerts & Sozzo, 2011). Thus, following the formalism of quantum theory, PLASTIC DISHES is a state that can actualize new properties, i.e., properties that are not properties of PETROLEUM BYPRODUCTS or DISHWARE, such as the properties "bright color" or "cartoon decal" since they are targeted at children.

Discussion

This example is simple; there is much work to be done to model the complex ways in which new situations influence the process by which one "puts a new spin" on an existing product or idea. Nonetheless, the example shows that it is possible to model the creative restructuring of a concept (e.g., PETROLEUM BYPRODUCTS) in a new context (e.g., kitchen) when it is considered from another perspective. The approach provides a formal model of what Rothberg (2015) calls Janusian thinking. It is consistent with theories of creativity (e.g., Gabora, 2000), and experimental data on how people use concepts (e.g., Aerts, 2009; Aerts, Aerts, & Gabora, 2009), and it has been expanded to incorporate larger conceptual structures (Gabora & Aerts, 2009), as well as how the same concepts are conceived of differently in divergent versus convergent modes of thought (Veloz, Gabora, Eyjolfson, & Aerts, 2011). Note how, in the quantum representation, probability is treated as arising not from a lack of information per se, but from the limitations of any context (even a 'default' context). Note also that prior to the realization that plastic dishware though lacking in elegance might be particularly appropriate for children, it is not true that this idea existed, nor did it not exist. Thus it is not appropriate to describe the creator's cognitive state as a collection of discrete possibilities some of which incorporate the existence of this idea. We cannot describe cognitive states of this type with conventional theories of creativity because they do not incorporate states of potentiality.

General Discussion and Conclusions

This paper outlined a multi-faceted initial attempt to investigate the phenomenon of cross-domain influence on creative innovation. First we showed empirically that the phenomenon is indeed widespread. Second we made a preliminary attempt to model a relatively simple form of cross-domain creative influence, exaptation, wherein a product from one domain is seen to possess new affordances when it is imported to another domain.

It is hoped that these two complimentary directions pave the way to a deeper understanding of how the complex richness of the world influences the creative processes by which that complex richness is amplified.

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