Creativity in the Twenty First Century

Giovanni Emanuele Corazza
Sergio Agnoli *Editors*

Multidisciplinary Contributions to the Science of Creative Thinking

Springer

Creativity in the Twenty First Century

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Preface

This book arises from our perceived necessity to offer a broad view about the multidimensional world of creative thinking, which is a truly domain-general research topic, although full of domain-specific implications. Indeed, creativity and creative thinking cannot be imprisoned into a single scientific discipline, as they are central topics in a number of cultural areas, wherein their study takes on distinct scientific approaches and sometimes different terminologies. In a search for a unifying fil rouge, we are fascinated by the extraction of the common principles for idea generation which underpin all domains of application in a transversal manner. Giving an in-depth view about some of the most recent theoretical and methodological approaches used in different disciplines for the study and analysis of creative thinking, this book is intended as a contribution to the foundation of the science of creative thinking.

The book contains an introductory chapter, proposing a unifying theoretical framework for the science of creative thinking, and four parts: "Theoretical Aspects of Creativity," "Social Aspects of Creativity," "Creativity in Design and Engineering," and "Creativity in the Arts." Each part offers a vision about both state-of-the-art and future trends, in the diversified forms of theoretical chapters, research contributions, reflection chapters, and educational approaches written by eminent international specialists. As we make no claim for exhaustiveness, this edited book should not be taken as a handbook, but as a well-harmonized ensemble of scientific contributions showing the intrinsic multidisciplinarity that characterizes the science of creative thinking.

Multidisciplinarity is in fact a fundamental element in the spirit of the Marconi Institute for Creativity (MIC), founded in 2011 at the joint initiative of Fondazione Guglielmo Marconi and University of Bologna, with the specific aim of contributing to the establishment of the science of creative thinking and its divulgation in educational and research milieus. Working on this book with the support of the CREAM European Project, funded by the European Commission FP7 Programme, we selected the chapters to be the expanded forms of the best papers presented at the MIC Conference 2013. The conference was attended by eminent scientists in the field of creativity and by the Fellows of the Marconi Society, who in their lives have produced inventions in the field of information and communication technologies, from the Internet to mobile telephony. In particular, the 2013 Marconi Award was presented to Martin Cooper, who is accredited to have led the team of engineers that produced the first cellular telephone in the world. The MIC Conference 2013 was therefore a unique event in which theory, practice, and entrepreneurial success have met together and dwelled upon the state-of-the-art and the future developments of a field which is destined to become central to the culture of our society.

The chapters in the book have all undergone rigorous review. The editors would like to thank the anonymous reviewers selected by Springer as well as the experts who helped us in the revision work: Felicity Anne Andreasen, Roger Beaty, Valentin Bucik, Mercedes Ferrando, Andrea Gaggioli, Martina Hartner-Tiefenthaler, Maciej Karwowski, Mariann Martsin, Ingunn Johanne Ness, Jelena Pavlovic, Roland Persson, Ugur Sak, Eric Shiu, Lisa Min Tang, Luca Tateo, Susana Tavares, and Taisir Subhi Yamin. In addition, our sincere appreciation goes to the editorial board of Springer, who believed in this project and worked with passion to turn it into reality. Finally, our warmest thanks go to our spouses and life companions, Susy and Titty, for their patience, support, affection, and love.

We hope you will truly enjoy this book, as we have enjoyed editing it.

Giovanni Emanuele Corazza
Sergio Agnoli

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Introduction

If we were asked to identify the main discriminant between the human species and all other living species, we could expect a nearly unanimous response in terms of our capacity of generating new ideas. Albeit rudimentary forms of generative behaviour have been identified in a few species (Kaufman et al. 2011), this is incomparable to the abilities possessed by humans. In other words, creative thinking can be argued to be the most peculiar activity of the human brain, and as such it has been an eternal source of fascination in the history of human progress. But for centuries, this ability to produce novelty has been interpreted as a mysterious gift, resisting any possible rational explanation. Indeed, the mere act of trying to explain creativity was seen as endangering inspiration and stifling the possibility for a flow towards the distant lands of fantasy. It was only around the start of the XX century that this veil of mystery begun to be raised, not surprisingly in concomitance with the great progress by the Viennese school of psychoanalysis, as testified by the publication by Freud of his paper on *Creative Writers and Daydreaming* (1908/1962). Wallas (1926), in his landmark manuscript devoted to the *Art of Thought*, was the first to attempt a description through a simple model

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of the creative thinking process, there subdivided into four stages: preparation, incubation, illumination, verification. In writing this book, Wallas was certainly inspired by many famous thinkers of the past, of which at least one deserves explicit mention here: Poincaré (1914/1952), who wrote with accurate detail about his dreamful experiences in idea generation for chemistry and mathematics. Indeed, the famous model by Wallas, still cited today in works on insight phenomena (e.g., Kounios et al. 2006), was only an intermediate step in the raising of the curtain, as it attributes the main mechanism for idea generation to unconscious thought, culminating into the illumination moment. But it was a fundamental first step, which opened the path towards the foundation of a new science: the science of creative thinking. Literature on the subject has been abundant since then; let it suffice to cite here the *Encyclopaedia of Creativity* by Runco and Pritzker (2011), where exhaustive reference lists can be extracted. We are on our way, but the final objective is yet to be reached, as testified by the difficulty that the subject of creativity encounters in becoming a full part of educational programmes at all levels of schooling.

The first element in the foundation of any science is a clear definition of all terms of reference. As a minimum, we need a clear definition of creativity and of creative thinking. This is actually still an open issue for debate, but we can state that the following definition embraces most of the fundamental elements: *creative thinking is the multi-dimensional set of components that lead an individual or a group to the generation of new ideas that have value*. If we simply define *creativity* as *the use of creative thinking*, we see that the two terms essentially coincide, and we can use them interchangeably. A few comments on this definition are in order. First of all, it is clear that such a definition leaves out that form of generation of novelty that we can attribute to the evolution of nature. In other words, we confine our attention to beings that think, and as such can exert a form of control (either aware or unaware) on their outputs. This includes both human beings and cybernetic machines endowed with artificial creativity (and possibly pseudo-emotions). Second, this definition makes it clear that creative thinking involves a complex process, where multi-dimensionality stems from cognitive, dispositional, emotional, social, and cultural elements, all playing an important role in driving the individual or group towards the wanted end result. Finally, for the process to be successful we require the generated ideas to be both novel and valuable. These two elements cannot be separated, for value without novelty is pure continuation, whereas novelty without value is pure craziness. We can define originality as the single attribute of an idea that includes these two fundamental properties, and propose the shortest form of definition: *creativity is the generation of original ideas*.

It is interesting to note that there exists an optimal level of originality. In fact, both novelty and value are historic quantities that derive from the projection of the new idea onto existing knowledge (either of the individual or of society). If the intersection with the past is very large, there is very little surprise, although probably significant utility. On the other hand, if the intersection is very, very small, the new idea will be radical and will face harsh resistance to its implementation in practice. Therefore, between these two extreme situations there must exist an optimal level of originality that balances surprise, novelty, value, applicability, and acceptance by society. The quantification of this optimal level of originality is still an open issue, which of course depends heavily on the domain in which creative thinking is applied.

Indeed, one of the difficulties, and at the same time of the beauties, of the subject of creativity is the fact that many elements are domain dependent, and it is a serious challenge to identify common principles, which we can identify as domain-general. But certainly, these common principles have fundamental relevance and will sit at the core of the science of creative thinking. Obviously, creativity is a transversal subject, which matters for any and all disciplines in the realm of human knowledge. This is exactly the reason why the literature is abundant in contributions from a wide set of domains, including the history of science and art, philosophy, psychology, science and art, sociology, design, engineering, management, artificial intelligence, and the list could go on. Confronted with such a formidable but somewhat scattered panorama, it becomes natural to select but a small subset of it, and be captivated into what can be considered as a narrow vision on a multisided subject. This is the problem of fragmentation in the field of creativity, which is well analysed by Hennessey and Watson (2015), where they call for a cautious de-fragmentation action, avoiding that the extraction of commonalities annihilates the domain-specific richness, especially with regards to education and to profiling persons in fields that are as separate as art and science (Botella and Lubart 2015). Therefore, as mentioned in Dorniak-Wall (2015), the question arises: what can be said at a general theoretical level about creative thinking, its process, the outcoming products, the creative persons and the environments in which they operate?

Theoretical Approaches to the Study of Creative Thinking

It is undeniable that, for a science to be considered as such, there is a need for a theoretical foundation, which must be able to account for at least the basic mechanisms that allow the generation of ideas in the human mind. The theoretical approach needs confirmation from experimental evidence, but it provides the guiding light for the design of the experimental campaigns themselves. If we were to simplify the process of creative thinking to the maximum possible level, we would find it difficult to describe less than three states: (a) gathering and structuring of information elements; (b) ideation; (c) verification of the effects. We argue that without either (a), (b), or (c), the creative thinking process cannot be considered to exist. The most obvious necessity is that of state (b): no ideation is tantamount to absence of creativity. On the other hand, without the verification given by (c), it is impossible to assess the originality of the idea. In other words, the process is always incomplete without a projection of the idea onto the real world. A slightly more intricate explanation is required to justify the necessity for (a), the gathering of information. This descends from the interpretation of creativity as a process of transformation of existing knowledge through the possible introduction of new information elements, recombination, association, etc. But without existing knowledge in a domain, ideation is virtually impossible in that very domain. This leaves out the concept of creativity ex-nihilo, i.e. the pure generation of new concepts without any predecessors, a divine style of creativity. Of course, the contrast between these two meta-interpretations of the idea-generation process has been the subject of a long debate for centuries, which we do not intend to re-open here. May it suffice to say that, as a minimum, in order to generate an original idea we have to be able to represent it in an understandable form (e.g., through language or images), and this requires knowledge of the description of previous ideas in the domain, without which communication becomes impossible. Now, it may be argued that in this minimal description we are missing one initial state, corresponding to the identification of the area where thinking takes place. This has been identified in various forms in the past, e.g. problem definition, focus definition, or problem construction. Now, while we definitely agree on the importance of this state in order to achieve results with acceptable efficiency, we maintain that this is not as fundamental as the other three. In other words, even if the mind is not set on any problem, and the attention is not focused on any specific area, the mere fact that a human being exists in a certain environment at a certain time instant allows his/her mind to use the available information to generate an idea that impacts and transforms the environment. Let's say that this is a much more casual (or inspired) instance of creative thinking, which includes the important case whereby *there is no time to focus*, as for example happens in improvised music, or in a creative immediate response to an unforeseen event. At any rate, to close the issue we can consider the focus definition to be subsumed by state (a), whereby the gathering of relevant information only makes sense when we have defined the criterion for relevance, i.e., the focus area.

Given these three fundamental parts of the process, different theoretical models can be generated by specifying to different levels of detail the components and strategies that the mind can use to move from state to state, or the improve the efficiency of the entire procedure. The states can therefore be subdivided into two or more sub-states, as necessary, also depending on the domain of application and the context (Botella and Lubart 2015). Let's see how this was translated in some of the most recognized models. The famous four-stages model by Wallas (1926) essentially splits the state (a) into parts: preparation and incubation. Both the preparation and incubation parts are concerned with a restructuring of the information gathered to resolve the problem at hand, with a difference which is marked by the level of awareness: while the preparation is performed at conscious level, incubation happens without any conscious control. Therefore, according to Wallas, ideation corresponds to a sudden illumination, and insight, a eureka moment. These are all real phenomena, which most persons faced with an ill-defined problem can experience, but they don't exhaust the list of possible mechanisms for ideation, as we will see in the following. Coming now to a much more recent model by Mumford et al. (1991), then revised in Mumford et al. (2012), we can observe a much finer subdivision into eight stages: problem definition, information gathering, information organization, conceptual combination, idea generation, idea evaluation, implementation planning, solution monitoring. Using our classification into three macro states, we can say that problem definition, information gathering, and information organization belong to (a), conceptual combination and idea generation belong to (b), and idea evaluation, implementation planning and solution monitoring all belong to (c). However, this more refined subdivision is useful for at least two reasons: it allows for detailed monitoring of the different parts of the process and the consequent definition and set-up of experiments; it can serve as a guide to train specific abilities and apply methods, with the overall aim to improve the performance of individuals and groups.

On the other hand, it should be clear that a complex eight-stages model can be well fit for instances of creative thinking in domains where the process entails a rather long interval of time (from days to several months or years), but it hardly fits the necessities of rapid response situations. This is indeed the domain of application of the geneplore model (Finke et al. 1992), which is actually an iteration between two states, subject to constraints: the generation of pre-inventive structures and the exploration and interpretation of these very structures. When this iteration happens in real-time, we have a very good representation of the inventive process taking place during musical improvisation or composition (in a flow state), creative writing, or painting. In short, it is a model that fits well with artistic production. Apparently, the geneplore model only maps on the fundamental states (b) and (c), respectively for the generation and the interpretation of the pre-inventive structures. However, if we were to admit the possibility to generate pre-inventive structures without previous knowledge, we would fall again into the case of divine creativity, which is definitely fascinating and possibly meaningful in a spiritual sense, but it escapes the boundaries of scientific exploration. Since the latter is indeed our scope, we must conclude that the geneplore model is incomplete, in the sense that it understates a phase of acquisition of expertise a competence in a domain, in order to enable the generation of pre-inventive structures and their attribution of value. In short, the fundamental state (a) underlies the geneplore model and it could take a lifetime of study and practice, while the geneplore model represents in a very effective way the real-time performance of a creative artist.

We conclude this review of theoretical models for the creative thinking process by analysing the so-called DIMAI model (Corazza and Agnoli 2013), which is a five states model identified by the acronym that serves at its name: Drive, Information, Movement, Assessment, Implementation. Essentially, the drive and information states can be grouped into the fundamental state (a), assessment and implementation both belong to fundamental state (c), while movement maps one to one on (b). It is useful to see why we felt it necessary to distinguish drive from information, as well as assessment from implementation. The drive state contains not only the focus definition, but also the emotional-motivational-cognitive spark that must be present in the thinker in order for the process to have good chances for success. In this sense, the DIMAI model is confluent, as it includes in the process the influence of personality traits, emotional states, as well as intelligence (Batey and Furnham 2006; Eisenck 1993; Feist 1998; Hennessey and Amabile 2010;

Kirsch et al. 2015; Sternberg and Lubart 1991, 1996). It should be clear that these elements are extremely important and quite different from the mere collection and organization of facts, information, and knowledge in general terms. Thus, this distinction within the fundamental state (a) between *drive* and *information* is very useful to help separate elements which are pseudo-objective as the pieces of information should be, from elements which are strongly subjective and yet essential for the success of the process. Coming now to the distinction between *assessment* and *implementation*, the border demarcation is given by the frontier that separates intra-personal processes from inter-personal relationships: in the *assessment* state we collect everything that happens within the individual, to convince him-/herself of the validity of the idea and to make the decision to take the risk and let the idea be exposed to the outside world; in the *implementation* state we account for all interactions that subsequently have to occur with other persons, be them from a small environment (e.g., academia or work), or intended as society at large, representing a complex cultural environment. Therefore, the separation of the fundamental state (c) into *assessment* and *implementation* is useful to include in an explicit way both intra-personal and inter-personal determinants for the creative thinking process.

As well discussed in Hennessey and Watson (2015) and Dorniak-Wall (2015), the discussion on theoretical models is far from being concluded, and several questions are still open in terms of generality vs. specificity to the domain, or correspondence to empirical evidence collected in either in vitro experiences or natural environments, as advocated by Botella and Lubart (2015). A clear path towards the further development of theoretical models is towards the inclusion of social aspects of creativity. In fact, the generation of idea, even when modelled as the activity of a single individual, is always an instance of a relationship. How to introduce these relational elements in a theoretical model is certainly an open issue today, and one worth pursuing further. Let's go deeper into the discussion of the effects of the environment.

From the Isolated Individual to the Social Environment

Certainly, the analysis of the effects of the environment on human behaviour is not a new topic in human and social sciences. Cultural psychology for example is concerned with how human behaviour and attitudes are rooted and embodied in culture. According to this approach, the human mind and culture are therefore inseparable and mutually constitutive. Creativity is no exception, as well presented by Glaveanu (2015), who sees it as an interactive process emerging out of the interaction between an individual and his/her cultural environment. As explained by the author, this interaction plays a fundamental role in the assessment of a new idea, which is an interactive referential process of comparison of the idea itself against the criteria for usefulness/aesthetics deriving from the relevant cultural domain. And the interaction develops both in the time and space domains, implying that creativity is actually a distributed relationship. This concept emerges also in the domain of socio-cultural analysis, see for example Sawyer (2006), Sternberg (2006), and Silvia (2008), where we find that developing an idea is always related to its acceptability by the domain's experts and audience. This socio-cultural perspective acquires central importance in the systems model of creativity by Csikszentmihalyi (1988), who presents creativity as the process emerging from the interaction of a person (i.e., genetic elements, experience, talents, etc.), a field (i.e., community of practice, network of stakeholders, gatekeepers, experts, etc.), and domain (i.e., accepted knowledge, methodologies, values, etc.). The systems model suggests that creative thinking interactions with the environment can be described according to different levels of analysis, from the most comprehensive to the most focused: social level, cultural level, field network level, and team level. The most interesting consequence of this multi-layer analysis is that, according to the level of interaction, the conditions that favour or stifle the creative process may vary. For example, we may organize a very creative team in a company (Walton 2015), which, depending on their specific position in the network field, may then turn out to be successful or unsuccessful in their efforts (Cattani et al. 2015).

Let's observe that the balance between the importance attributed to the social aspects of creativity and the role of any single individual within the network is very delicate. On the one hand, considering creative thinking as a process that happens within a single individual totally isolated from the rest of the world is a false myth that has been contradicted by extensive research (see for example Amabile 1983, 1996). On the other hand, the investigation of the interaction between the environment and the individual should not be arrested at the network level, but should return onto the individual to understand the modalities, the role, and the effects that these social interactions have on the creative thinking process taking place within one's mind. In other words, in the science of creative thinking it is necessary to find a balanced fusion of the approaches based on the individual and on the social aspects, avoiding a contrast which would be indeed artificial. The analysis of past eminent personalities and of the environments they lived in can be an exceptional source of insights, as pursued in the historiometric research by Simonton and Ting (2010). In the same way, the case studies proposed by Sgourev (2015) are effective exemplifications of a system approach to the study of creative thinking which joins micro (individual) and macro (socio-cultural field) levels and their dynamic interdependence, which turns out to be essential for the emergence of exceptional creative products.

Needless to say, the social and cultural aspects are always strongly related to the geographic displacement of the network. Nowadays, the connectivity can easily bring together international groups, but we have important cases in which language and borders are very effective walls. The most important instance is undoubtedly that of school education in general, and training for creativity in particular. As described by Zhou and Valero (2015), by comparing the cases of China and Denmark, it is clear that diversified culture indeed generates different drivers and barriers to the introduction of creativity in education. It is an interesting question to verify whether the understanding of cultural influences on the education of creative thinking can be exploited for the selection of the most efficient strategies to improve the educational curricula in different countries.

Let's now turn our attention to domain-specific aspects.

Idea Generation in Science and Engineering

The first question to be addressed when speaking of creativity in a scientific or technological domain relates to whether this corresponds to a discussion on problem solving. In fact, this kind of terminology is so widespread that in many theoretical models the process starts with a *problem definition* stage. This has critical importance not only to direct the thinker's attention towards a specific area of knowledge, but also to put into evidence all of the constraints, boundaries, and requirements which define that specific area. This could then be transformed into a discussion about the broadness of the term *problem*, i.e. on the relative weight that we place on those constraints. Honouring the importance of the etymological point of view, since medieval times the word *problem* stands for *a difficult question proposed for solution*. We could say that science, in its most general understanding, tries to answer the difficult question: *Which are the laws of nature*? Therefore, new ideas in science could in general be seen as the result of a problem-solving exercise. On the other hand, engineering, and the development of new technology in general, aims at progressing beyond the state of the art. In some cases, it is evident that the present status can and should be improved, due to *problems* which are visible to everyone, or at least to the experts in the field. But we cannot rule out the instances of idea generation in fields that were not at all perceived as *problems* nor necessities. If we can accept this as a fact, then we open the possibility to go beyond mere problem solving: even in technical fields, idea generation can be exerted in any focus area of interest, irrespective of the immediate perception of urgency or necessity, i.e., with very loose constraints and requirements. Years after, we could find that people cannot do anymore without the innovation introduced at the time of its generation: technology has been pushed over an area that was not perceived as a problem, and only a posteriori has it become a necessity. In passing, freeing up creative technical thinking from the narrow boundary of a problem brings it closer to the artistic approach, and also gives room for serendipitous findings, i.e. those instances whereby we find something that we were not looking for: it is clear that we have not *solved a problem*, and yet we have generated a concept which may turn out to be extremely useful.

A second distinction which merits consideration is between the terms *discovery* and *invention*. If science is only devoted to the understanding of nature, new ideas should be intended as discoveries. Yet, understanding can take on different approaches and methodologies, and these can be considered to be abstract products of human minds. We consider it to be entirely possible for a scientist to *invent* a new method of analysis. Furthermore, when one starts to play with nature, setting aside any and all considerations of the consequences in terms of ethics or sustainability of the world as we know it, then it becomes easy and natural to accept inventions in terms of, e.g., synthetic biology, genetically modified molecules, new hybrid species for flora and/or fauna. In the field of engineering, on the other hand, the primary goal is to create artificial systems, machines, algorithms, protocols, that perform functions of utility to human beings. Are these concepts always *inventions*? The immediate answer would be positive. Still, we can dwell on a distinction between those artificial systems that simply mimic nature, trying to reproduce artificially what would be a natural element of the world, and those more challenging products of our mind that actually extend the capabilities of humans and/or of nature. For example an artificial limb, which certainly requires wonderful technology, in-depth understanding through discovery, and possibly a number of patents on materials and algorithms, belongs to the first category. No human being can advocate to have invented an arm or a leg. In the absence of a single term, we propose to identify these ideas as *creative reproductions of nature*. Here, creativity does not lie in the subject itself, but rather in the way it has been artificially reproduced, in the number of functions it can perform, in the way it can be manufactured. On the other hand, we can invent devices and systems that can extend our capacities without any significant resemblance in nature. A fitting example is that of a car, intended as a vehicle moving on wheels connected by axes. The function that it delivers, however, is that of transportation over the earth surface, which is clearly pre-existing the concept of the car. Since this kind of moving platform has no equivalent in nature, but the function does, we can identify it as a *creative extension of capabilities*. A third category exists, including those inventions that allow human beings to live in conditions which are impossible in nature, and as such introduce unprecedented possibilities. Examples include: the submarine for life under the ocean; the airplane for life in the stratosphere; the space shuttle for exploration beyond the earth atmosphere. Each of these is actually an example of a meta-invention containing a number of smaller ideas, i.e. they are systems. We define this third category of inventions as *creative extensions of the conditions for life*. What about the Internet? Should we simply say that it is an extension of the capacity to communicate for human beings? Actually, it is much more. It is an extension of connectivity, of computation capability, of storage, of presence in remote place, of knowledge management, of socialization, of idea generation, of reality in virtual and augmented forms. Therefore, we can preliminarily conclude that the Internet contains all three elements: it is a reproduction of nature, when for example it mimics the interaction with a person represented by an Avatar; it extends human capabilities, allowing to retrieve information on any topic, anywhere and anytime; it extends the conditions for life, by introducing a number of virtual worlds which require multiple personalities for a single human being.

Creativity in the field of science and engineering has therefore its own peculiarities. The interesting fact is that advancements in different scientific and technological fields can be associated with specific inventive principles; the extraction of fundamental rules can even allow to think that the principles of a determined field can be transferred to other fields, in a powerful interdisciplinary approach. This can be certainly possible through a brilliant use of analogical thinking, which is well described by Helms et al. (2015), who present a new methodology to solve technical problems by creating biologically inspired solutions. In this case, the *creative reproduction of nature* offers the inventive principles that guide the creative thinking process in mechanical engineering problem solving. Interdisciplinarity in the scientific domain can be interpreted as the fluid transfer of knowledge (theories, methodologies, techniques, etc.) from one area to another, to acquire multiple points of view through which one can understand, reproduce, or extend the laws of nature. Analogical thinking is evidently the fundamental enabler of this transferring of concepts (Dunbar 1995), as exemplified also by von Thienen and Meinel (2015), who use the principles of design thinking to create a new form of collaborative problem solving during psychotherapy, and demonstrate the effectiveness of this method. Other principles guiding the inventive process have been identified and extensively described in the literature, in particular by Altshuller (1984) in his theory of inventive problem solving (abbreviated from the Russian translation with TRIZ). Starting from the impressive analysis and classification of over 200,000 technological patents, he found that only a very small percentage of these were consistently new, and therefore he passed on to extract regularities and patterns at the basis of the problem solving process. His theory is today applied in a number of companies and mechanical engineering schools (Beccattini and Cascini 2015) to improve and systematise the inventive process. Improvement of the creative process can of course also be tackled by addressing the individual characteristics that foster and enable problem solving capabilities. Multidimensional approaches, for example, try to find latent models predicting problem solving and creative abilities (Kirsch et al. 2015). Thanks to the systematic analysis of the creative thinking process within scientific and technical domains, the identification of clearly defined stages and abilities subsuming the process is now possible, as Cropley (2015) shows for the engineering domain. This approach allows not only to describe the conditions and abilities favouring creativity and the inventive process, but also to introduce pertinent interventions inside technical curricula in the education system. A future challenge would be to design innovative strategies for using the different abilities in the various stages of the process, to optimise the creative product.

An Artistic Home for Creativity

Undoubtedly, one of the most widely accepted notions is that creativity is intrinsically connected with art and artistic behaviour. Since the earliest times of human civilization, artists were considered to be the repositories of the holy fire of inspiration that leads to creativity. Other forms of idea generation could therefore be seen as inferior forms of reproduction of the artistic creative approach. These and other similar myths have survived and still populate the literature on creativity, creating an apparent gap between the worlds of artistic composition/performance versus scientific/technologic production. However, if we are on the path towards a unified science of creative thinking, it is necessary to first highlight the basic commonalities and then discriminate on the specificities. Let's start by introducing a scientific definition for inspiration: *inspiration is the mental process that starts from the aware or unaware input of an unforeseen, unexpected, unplanned, irrelevant conceptual entity and terminates with the generation of a pattern that is afterwards seen to be relevant to one's focus*. We then say that the final product was inspired by the apparently irrelevant conceptual entity. Thus inspiration is actually a fundamental process, that in the previously mentioned DIMAI model for the creative thinking process corresponds to the *movement* mental state. In essence, no matter what the application area, the generation of original ideas always entails the processing of irrelevant information. From this point of view, artistic inspiration can be elected as the paradigmatic form of generative process, and at the same time it can be freed from long-standing myths of semi-divinity and peculiarity of the creator. In particular, the strange, psychotic, and unconventional behaviour often exhibited by artists would seem to suggest that rules are harmful to creativity, which is on the contrary nurtured by living at the margin of society. This is indeed a myth: while it is true that eccentricity may be useful to the introduction of irrelevant elements in one's thinking, as well as to lowering the barriers that are erected by placing reputation at a prime, we cay say that it may be a sufficient condition, but by no means necessary. In other words, once we realize that open-mindedness is the essential skill to allow the co-existence of relevance and irrelevance in the same thinking process, and that the ability to move from there is the key to generate ideas which are both novel and valuable, then these skills and these processes can be nurtured and applied without affecting one's external behaviour. Artistic inspiration can live side-by-side with social acceptance.

A confirmation of the scientific foundation of creative performance in artists is certainly given by neuroscience. Through the analysis of the neural structures subsuming creative behaviour, neuroscience reveals that creative thinking is sustained by basic cerebral interconnections between areas associated with specific cognitive functions. Neuroscience allows to associate bodily evidence to musical creativity, showing the activation of neural networks during music composition (Rahman and Bhattacharya 2015). Moreover, monitoring the brain activity gives a corporeal image to real-time musical phenomena, such as improvisation, showing how this behaviour is intrinsically linked with expertise. A broad network of brain regions is associated with musical improvisation, which is highly influenced by the performer expertise: the longer the experience in improvisation by a performer, the stronger the neural associations (Rahman and Bhattacharya 2015). However, the neuroscientific study of creativity is a relatively new field, that has yet to stabilize some important methodological issues. First of all, there is a large variety of methods to monitor the brain's activity (e.g., EEG, fMRI, PET), leading to variable agreement about the brain areas involved with creativity (Dietrich 2004; Dietrich and Kanso 2010). Secondly, and perhaps more importantly, creative thinking is a very complex mental process involving a multitude of skills and traits, as well as a number of cognitive, social, and motivational abilities. This complexity is clearly hard to appreciate with a neuroscientific approach based on the monitoring of a single task, such as for example the RAT (Remote Associates Test) by Mednick (1962). Notwithstanding these issues, the value of neuroscience in giving concrete evidence to the functioning of the human mind cannot be overestimated: it gives confidence and solid grounds to higher level theoretical approaches.

The systematic study of creative thinking in the artistic domain gives higher awareness on the generative process and, at the same time, offers insights on possible strategies and approaches to evolve artistic education. The key appears to be the search for an optimal balance between three opposing elements: talent and skill, freedom and discipline, inspiration and theory. In fact, exceeding in any of these extremes holds the risk either of stifling creativity with an over-disciplined approach, which does not allow to deviate from accepted theory and styles, or of becoming an inefficient and ineffective observation of talent and unfocused search for inspiration. This delicate balance must serve to activate the necessary attentive and motivational resources, and to this purpose *teaching by projects* appears to be one of the most effective educational methodologies. Similarly to the *problem* in the scientific field, the *project* assumes in the artistic field the key role of activating field knowledge, the necessary skills, and the required thinking strategies (Journeaux and Mottram, 2015): it represents the focusing method to concentrate the attentive, cognitive and attitudinal abilities of an artist. The main point is that, even though we are looking for some form of inspiration in order to use our talent, through the disciplined use of the skills that we have developed, the definition of clear objectives and the setting of boundaries in terms of both quantity and time are not only helpful but essential in order to educate a young artist. It is both a matter of management of spontaneity, ingenuousness, or disengagement, and a disciplined process towards the development of skills and the flexibility in their use (Sintoni 2015).

The increasing understanding of the fundamental rules regulating the creative process in the artistic domain is reflected also in the results obtained in artificial intelligence, and in particular in computational creativity. Even though we are at great distances with respect to the levels attained by human creativity, interesting results have been obtained by reproducing creative artistic behavior through simulation by *intelligent* machines. In his review of *artificial* creators, Sawyer (2006) analyzed software-enabled machines that generate paintings, poetries, chemical products, etcetera. Interestingly, the tools of mathematical-statistics have been used to simulate highly sophisticated artistic performance in accordance to the style of a specific artist (Ghedini et al. 2015). Every artist indeed is recognised by his/her own style, i.e., a personal and reproducible (even if subject to a constant process of refinement) generative schema. Thanks to the analysis of the corpus of sequences the creator has composed, computational techniques can derive and reproduce the creator's style in different domains, such as music composition, music harmonization, and text writing. Of course, one can question the effective level of creativity that these machines can produce, if any. The main criticism stems from the fact that these techniques do not include in their generative process emotional elements, which are however central driving elements in the human creative process. Only when artificial intelligence will be able to endow a machine with emotions, we will be able to start the assessment of the outcomes of computational creativity. Nevertheless, computational creativity is a valuable element in the study of the creative thinking process, which can offer additional insights to the understanding of the dynamics defining the process. A minimal lesson to be learnt is that if a machine can produce results that are in some form surprising, then there are vast possibilities to define, explain, teach and apply creative thinking methodologies to the much more powerful human beings.

Conclusions and Future Directions

We believe the science of creative thinking is based on solid principles and consistent facts, but the path towards maturity is still long and the open challenges are many. The first diachronic challenge is to reinforce the roots, based on a factual and methodological investigation of the creative thinking process characterizing geniuses of the past. There is a need to go beyond an anthological narration of the lives and personalities of eminent persons (artists, scientists, inventors, etc.), and move significant steps towards the understanding of their particular life conditions, as individuals immersed into a specific environment that favored their rise to excellence. The extraction of generative, evaluative, and motivational principles guiding past geniuses is now recognized as a fundamental matter of study, as testified by recent editorial ventures (Runco 2014). The study of past eminent persons can be interconnected by following a historiometric approach (Simonton and Ting 2010) which, in conjunction with psychometric analysis, can open the scene to the opportunity of looking at history from a new perspective: not a mere collection of facts, but a complex and dynamic ensemble of ideas. Revisiting our history on the shoulders of past personalities can provide a new interpretation of our cultural heritage, and a new sense of identity as being part of a well identifiable flow of ideas. The science of creativity would then become intertwined with the evolution of our societies, and as such it should be expanded to all knowledge domains. Only in this way a map of domain-general and domain-specific elements characterizing creative thinking through the ages can be drawn.

Focusing the attention on the synchronic study of creativity, we feel it is urgent and necessary to bring together the scope, theories, and methods of cognitive and neuroscientific investigations of creativity. The joint use of a behavioural and functional interpretative models with the evidence provided by neuroscience, holds the potential to offer new significant avenues to the study of creative thinking. In this context, artificial intelligence could be used to obtain a reference to compare human creativity and computational creativity. Another area that requires large investment in the future is the study of the influence exerted by emotions on the creative thinking process. Even if emotions, and in particular surprise, are a part of the definition of creativity (e.g. Simonton 2012), the study of their role in the creative process has been concentrated mainly on motivation (Amabile et al. 2005) and mood states (Dawis 2009). Much more can be said about the effect produced by distinct emotions (happiness, sadness, anger, fear, etc.) on the creative thinking process. Moreover, the interaction between creative abilities and emotional intelligence (Ivcevic et al. 2007; Sanchez-Ruiz et al. 2011) must be further explored, and we can expect that not only the ability to regulate and manage emotions will translate into higher effectiveness of the entire process, but also the capacity to induce emotional states into others will turn out to be the real enabler for creative environments.

While the science of creative thinking expands its application fields, further measurement approaches must be developed to catch the complexity of the creative thinking process. Not only the quantification of single cognitive abilities is required, but new measurement systems able to take into consideration cognitive, emotional and personalities components in an interactive relationship with the social and cultural environment. The identification of creative profiles within different *natural* environments, as indicated by Bottella and Lubart (2015), points to the fact that profiling shall not be limited to the individual but expanded to the environment where the individual performs.

We must also not forget that a field of investigation does not become a science unless it has visible influence on educational programs. Creativity in schools is typically equaled to teaching of arts. Although this is certainly valuable, we are far away from the systematic introduction of the science of creative thinking into national and international educational systems. Theories and methods for idea generation should become a self-standing discipline, with possible applications to many domains at the choice of the student. An interesting avenue, largely unexplored, is to consider the teaching of creativity as a life-long process that includes elderly people in the audience. History has shown that most of the important creative products are generated at a young age, but is this due to simple aging of the brain? Or, perhaps, is there a fixation of certain attitudes that impede creative activity, such as the immediate rejection of irrelevant information, rapid assessment of ideas, unwillingness to put one’s reputation at risk? And are there ways to overcome and actually turn around these attitudes? All of these questions are yet waiting for answers.

A final challenge concerns all researchers and practitioners who are involved with the science of creative thinking. In the information society, where facts, data, and knowledge in general are in principle available to everyone, creativity becomes the essential activity that distinguishes human beings, and as such it is a necessity to their own dignity. Therefore, the development and dissemination of the science of creative thinking becomes a mission for benefit of every individual and of society in general, and everyone involved in this field should feel invested by such a mission.

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The Defragmentation of Creativity: Future Directions with an Emphasis on Educational Applications

Beth A. Hennessey and Malcolm W. Watson

Introduction

In 2010, Beth Hennessey and Teresa Amabile published a comprehensive review of the creativity research literature in the *Annual Review of Psychology*. In selecting which articles to review, rather than fall prey to their own potential biases, Hennessey and Amabile decided to rely on the consensus of experts. They started out by polling 21 eminent colleagues—all prolific researchers and theorists in the field of creativity research—asking that they nominate up to 10 articles or books, published since about 2000, that they considered to be "must have" references. Surprisingly, consensus was not to be had. In fact, this call for nominations did nothing more than add to their confusion. The poll yielded 110 suggestions of specific journal articles, book chapters, books, or entire volumes of a journal devoted to a particular topic. Of the 110 nominated references, only seven were suggested by two colleagues, and only one was suggested by three colleagues. Rather than make the reviewing process easier, this exercise only served to underscore the marked diversity of opinion and overall fragmentation of the creativity field.

Over the past few decades, there has been a virtual explosion in the creativity literature of topics, perspectives and methodologies. Yet careful scrutiny of the literature shows that few, if any, "big" questions are being pursued by a critical mass of investigators. In many respects, the scholarly understanding of the psychology of creativity has grown amazingly sophisticated, and contemporary researchers

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now bring to the table an ever-expanding variety of analytic methodologies, disciplinary training and backgrounds. The problem, however, is that investigators in one subfield often seem entirely unaware of advances in another. Many creativity researchers (ourselves included) were trained as experimentalists—systematically manipulating one or two variables at a time and making every effort to keep all other factors constant and controlled. This is the tried and true scientific method after all. Yet some experimentalists have become so focused on the minute details of a specific creative situation or participant cohort that they fail to seek the bigger picture. As a result, research is often carried out at only one level of analysis (e.g., the individual or the group) and within only one discipline or subfield at a time. Of course, this problem of isolation of sub-domains of research is not unique to the creativity field. It tends to pervade many disciplines of inquiry (Ambrose 2005; Persson 2012, 2014).

In its final form, the message of Hennessey and Amabile's *Annual Review* was that researchers and theorists must now work to develop a systems view of creativity. "The 'whole' of the creative process must be seen as much more than a simple sum of its parts" (Hennessey and Amabile 2010, p. 571). Creativity must be operationalized as a result of a system of interrelated forces operating at multiple levels and requiring interdisciplinary investigation. This call for reform seemed to be sound, but it is easier said than done. Might there be some hazardous consequences involved when researchers attempt to develop a unified systems model of creativity?

Since the publication of the 2010 review, the call for a de-fragmentation of the field has, in fact, been referenced by a variety of investigators and theorists. Many appear to agree that an integration of the creativity literature is long overdue. For example, some of the important work that was shared at the 2013 conference at the Marconi Institute for Creativity in Bologna was directed toward that goal. We believe that it would indeed be a big step forward, a significant accomplishment, if we could actually construct what appear to be useful systems approaches or, dare we envision, one single, all-encompassing systems model. The construction of such an all-encompassing model would serve as an impetus for future research and would be of great use in synthesizing the literature and coordinating research efforts. In our view, it makes good sense to continue working in this direction.

After all, this is the course of action that is generally taken in any scientific domain. Preliminary research sets out to test one or more hypotheses. Soon, scientific models are constructed to depict or describe the phenomena in a way that makes them easier to understand, visualize and quantify. Over time, these initial models lead to the generation and systematic testing of new, more nuanced, hypotheses and models. Yet models run the hazard of sometimes oversimplifying reality because they cannot include all aspects. If they then end up complicating researchers' views of reality or taking them down wrong paths, they cease to be useful models.

Importantly, as the scientific inquiry of a phenomenon grows and becomes more and more multi-faceted, there sometimes comes a sort of tipping point, a juncture at which it is no longer possible to synthesize the scholarship, no longer possible to extract commonalities across the many sub-areas of inquiry appearing in the literature. At such a point, creating a useful scientific model may not be possible because there would be too many phenomena left out or left unexplained. The empirical investigation of creativity seems to have reached this point.

Although we believe that researchers and theorists must now work to develop a systems framework of creativity that would support scientific model construction, the primary goal of this chapter is to voice our concern that this work does *not* end up leading to a sort of wholesale reduction of the field and to the creation of models that do not clarify our understanding of reality. In addition, we engage in the empirical study of creativity not ultimately for the sake of research but in order to better understand how to promote and "grow" creativity, and when we remind ourselves of that real-world focus, we come away questioning whether a so-called systems model or "grand theory" will do much to guide us in applied settings.

Integrative Models of Creativity

What would a truly integrative systems model consist of? How can we construct an integrated model that captures the highly complex system of interrelated forces operating at multiple levels to produce creative outcomes? Does it at all make sense to ask researchers and theorists to work to construct a systems model that simultaneously accounts for so-called "Big-C" (Einstein level creativity), "Pro-C" (the creativity of R&D developers working on the next "big thing"), "Little-C" and "Mini-C" (everyday level) creativity (see Kaufman and Beghetto 2009)? Perhaps this is not a realistic goal. Perhaps it is not even an important goal. Here are some related questions. Should both trait (personality and intelligence) and state (situation-specific) measures of creativity be included in our overarching model? Could one model adequately capture the creativity of children as well as the creativity of adults, both novices and experts in their fields? And would it make sense to incorporate into our model data collected worldwide, or would multiple models be necessary to account for demographic, ethnic and cultural distinctions? Moreover, if we are to subscribe to some recent research showing creative performance to be primarily domain-specific (as opposed to cutting across domains), should not even the most integrative model of creative behavior also focus on only one area of expertise at a time?

In 2011, John Baer published an especially thoughtful paper entitled *Why Grand Theories of Creativity Distort, Distract and Disappoint*. It is Baer's contention that we will never succeed in constructing an all-inclusive "grand", or systems, theory. Baer well understands the appeal of such an approach and reminds readers about how the study of particle physics was rejuvenated by just such an all-encompassing model. Yet he cautions that it is unlikely that any one theory or model will ever adequately describe, as he puts it, "the many very different kinds of cognitive [/behavioral] processes that underlie creativity in diverse domains" (p. 73). As Baer argued, trying to force such a theory is bound to impede both theory and practice and lead to more misunderstandings than worthwhile breakthroughs.