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Learning scientific creativity from the arts

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ABSTRACT
Examining scientific creativity through the lens of artistic practice may allow identification of a path towards an institutional environment that explicitly values and promotes transformative creativity in science. It is our perception as an artist and natural scientist that even though creativity is valued in the sciences, it is not institutionally promoted to the same extent it is in the arts. Acknowledging creativity as acts of transformation and central to scientific pursuit, actively utilizing chance and failure in scientific experimentation, are critical for step changes in scientific knowledge. Iterative and open-ended processes should be modeled after insights from a range of practices in the visual, performing and media arts. Successful institutional implementation requires training through a long-term process of unlearning and learning, organizing interactions to critique results, designing experiments to contain trial and error, and building common and individual spaces that promote chance encounters across disciplines and with non-academic sectors. As a natural scientist and an artist, we call for bringing such a transformative creative approach into scientific practice as a guiding principle for organizational and cultural development of the university.

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Introduction

Comparing the arts and sciences, not everyone may think of natural science as a creative endeavor in comparison to artistic practice. For the longest time, science was rather associated with discovery of what is already there than actual creation (Barasch, 1985). It is telling that the word 'creativity' only appeared about one hundred years ago (Whitehead, 1978) and for the most part stayed in the realm of artistic production, despite the close relationship of art and science noted by many contemporary scientists (Root-Bernstein et al., 2008). Even Goethe considered his scientific theory of colors (Fig. 1) his greatest achievement, not his poetry, illustrating how close artistic and scientific pursuit may align. Yet in natural science, you are taught the answer, in arts, the questions, process and material production. From our point of view as an artist and a natural scientist, we strongly argue that close observation of artistic creativity (Collingwood, 1937), defined as ideas and actions that transform laws, principals, materials, and thoughts both of the artist and the audiences, can be informative for scientific progress. Important lessons about educating for and promoting creativity in the sciences can, in our experience, be learned from studying the creative process in the arts. The following comments collate our thoughts from an artistic and natural science point of view.

Framing the issue

Both arts and sciences rely on a foundation of mastering methods and conceptual tools that require familiarity with the norm in order to question it. As much as a visual artist has to comprehend and engage the histories of visual, cultural, conceptual and social questions of the past and present, and deal with fundamental laws and skills governing the conception, production and reception of visual art, the scientist must have a basis in, for example, statistical methods, chemical reactions or ecological theory. Both artist and scientist must then synthesize their aptitude beyond just art or science, beyond following rules and relying on imitation to become creative. Key is often a conceptual advance rather than a sole focus on the physical product itself. This can be thought of as the "transformative moment". Even appropriation and placing known objects into new contexts can develop original thoughts, exemplified by Sturtevant's copies, Duchamp's ready-mades, or the Post World War II explorations in spontaneous musical compositions in BeBop based on standard tunes raised by Charles Parker. But simply copying what has been done before, without arriving at new insights, is neither creative nor transformative. One may argue it does not even constitute practicing art or science at all.

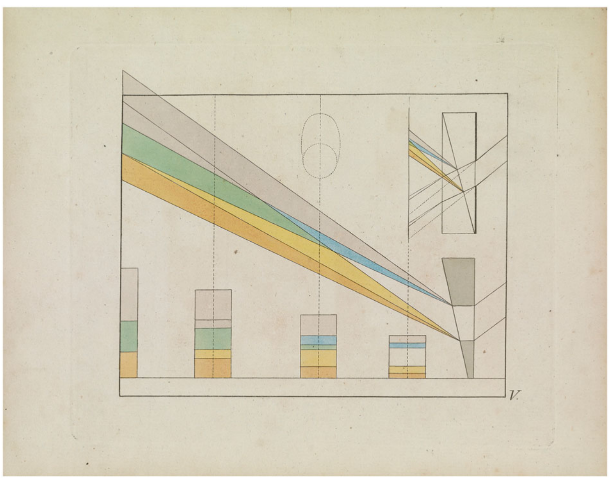

Fig. 1 Goethe's theory of color and diffraction of light. Even though J.W. von Goethe is known today mainly as a literary author, he conducted basic science throughout his life and considered himself as much a scientist as a novelist and poet (reproduced from von Goethe (1810); image in public domain)

Relying on cognitive skills, conceptual tools, the knowledge of precedents and processes, along with the merger of intention and intuition guide 'what-if' questions, and are important assets in the toolbox of transformative artistic creativity. Common in art but rarely practiced in the natural sciences—and a critical aspect for a creative spark—is the ability to make associations between or blend (Turner, 2014) disparate parts of knowledge and experimental evidence. This is called the art of intelligent perception (Bohm, 1976). We agree that the degree or probability of creativity in science relies to a certain degree on personal aptitude (Feist, 1998), as well as acquired knowledge and skills with important insights for teaching creative inquiry (Mumford et al., 2010; Scheffer et al., 2017) and developing creative potential during a career (Mumford et al., 2005). In addition, as we argue below, the probability of creativity in natural science is a direct function of a broad range of situational attributes that can be manipulated. These situational attributes are in our opinion not sufficiently considered by natural scientists and science administration for promotion of creativity. Similarly, the explicit nurture of creativity is all-too-often absent in scientific pursuit and its education even after a long history of studies examining scientific practice including aspects of creativity (De Bono, 1973; Latour and Woolgar, 1979). We do not intend nor are we qualified to advance the scholarship on creativity from a psychological or philosophical point of view or provide an in-depth overview of the associated literature (e.g., DeHaan, 2011; Lehrer, 2012; Turner, 2014). Rather, by insisting on an important responsibility of scientific institutions to provide the organizational foundation for individual creativity, we intend to move this discussion on the framework of artistic creativity to the center of the academic discourse also for the natural sciences.

Entry points for organizational support of creativity

Here we discuss lessons for scientific creativity that may be gleaned from an observation of artistic creativity through an organizational lens. Even though creativity can in many cases be an individual pursuit, it is also relevant to groups and networks, and includes audiences and stakeholders. Most mechanisms that promote scientific creativity possess both individual and organizational dimensions to varying extents and we consider these jointly for the purpose of our discussion. From our art and natural science perspective, we propose to prioritize the following six entry points for promoting scientific creativity: acknowledging creativity as an essential asset; recognizing chance in identifying new directions; constantly critiquing one's own research, as well as each other's; trial and error to accelerate discovery; allowing mental space to reflect on scientific results or plans; and value creativity to a greater extent in your own work, in the work of your advisees and your institution. These entry points for the natural sciences are discussed below and compared to the arts.

1. Creativity—that is, developing original ideas and concepts—is the basis of artistic practice. But as with art, natural science requires creativity and individuals, as well as institutions must acknowledge the pivotal importance of creativity as a defining feature of scientific advancement. It is not, as Kant (1790) put it, a matter of learning and copying methods to arrive at a scientific advance alone. As with art, so does science require creativity. Natural scientists must approach their inquiry with the same rigor and expectation for novelty as artists do, which in our experience is not sufficiently the

case despite longstanding investigations into scientific innovation in general (Knorr-Cetina, 1981). Recognizing that natural science requires creativity, we can appreciate that artistic practice may even provide a template for creativity not only for scientific practice by faculty (Hoffmann, 2012) but also by technical staff in many natural science disciplines (Wylie, 2015). We therefore suggest that an artist's viewpoint may provide researchers and research organizations with a template to advance creativity in the natural sciences. Making creativity a primary measure of success by considering it a significant evaluative metric concurrent to publication records and other assessments would add structural support for creativity in science. The natural sciences could then also be called a creative profession.

2. Chance has often been quoted as an important factor in promoting creativity. The apparent chance "discovery" of photography by the artist Louis Daguerre resulted from accidental spillage of mercury in a cabinet storing silver-plated copper plates revealed the latent image on a plate. Similarly in science, Wilhelm Röntgen discovered x-rays in 1895 when a chemically treated screen placed in the laboratory started to glow by exposure to a shielded cathode lamp; and Alexander Fleming observed in 1928 that staphylococcus was inhibited when a petri dish was accidentally left on the laboratory bench, leading to the development of modern antibiotics. Allowing for chance to occur in natural science, or even promoting and recognizing valuable chance results, is anything but trivial. Most scientific experiments are designed and taught to reduce chance to allow only certain questions to be answered, meaning that today's scientist is often ill prepared to utilize unexpected results. On recognizing chance, Louis Pasteur famously remarked during a lecture at the University of Lille in 1854 that "in the fields of observation, chance favors only the prepared mind". A scientific study too often develops along the script outlined in a proposal, rather than changing direction—as in many artistic processes—when the second step is fully dependent on how the first step turned out. Funding in the sciences and reporting should be built on promoting chance rather than measuring success strictly by compliance with a plan. Scientific proposals may lead to more important science, if the transformative possibilities of a question were valued to a greater extent than simply meeting the presumed or already-demonstrated feasibility of the experiment.
3. In art, self-critique and critiquing by peers often occurs during the entire creative process. Each brush stroke is evaluated, each move in a dance routine scrutinized as part of the process of creation—meaning work can be improved in the moment. In the sciences, success or failure of an experiment is all too often evaluated only after weeks, months or even years of work, when it is too late to change direction or repeat the study in a different way. Critiquing in the sciences typically comes at the end of a long process, and often in the form of cursory comments that either lead to the acceptance or rejection of a publication or proposal. A more creative approach in science would include having a continuous opportunity for feedback built into the scientific process, to allow for course correction in the research that could result in a different experimental design or even changing the question.
4. A heuristic approach in art allows many iterations to get the line in an artist's drawing just right. Egon Schiele purportedly drew like a maniac and threw most drawings in the fireplace if he did not like them. Today we judge his creativity from the superb works that have survived which are the result of many iterations of trial and error. In comparison, scientific experiments are usually expected to give an answer at first attempt with no time to perform another one, making trial and error a long-term process in the sciences. Error is therefore not seen as a practical intermediate step sufficient for reaching immediate scientific insights or essential for reaching a creative goal. Creativity could be promoted by starting with shorter and more varied experiments where the vast majority are expected to 'fail', but lay groundwork for selecting the most promising next step. Concrete modifications in how natural science is organizationally supported and practiced may include: consideration of the time and space allocated to trial and error; expectation by graduate, tenure or hiring committees to demonstrate failure, as well as to reward iterative research rather than unidirectional experimentation; and high-risk project funding for outcomes that are not already prescribed but the result of open-ended exploration for at least part of the study to allow unrestricted creativity.
5. The subconscious or "inspiration", the proverbial kiss by the artist's muse, is described as the mainstay of artistic creativity. In science, this may translate into the scientific reflection necessary to examine data, sketch out a proposal or plan an experiment. Mental or 'empty' (Scheffer et al., 2017) space where scientific creativity is strongest is not all that different from a focused state of mind containing irrational elements or intuition (Popper, 1935). Mental space to reflect on scientific results or plans is typically not given any priority in the sciences but scientific progress is assumed to be a mechanic outcome of planned daily activities. Providing that mental space requires organizational and individual effort. Individual preparation may include establishing cues for switching off and then on again, taking breaks, allowing time to develop an idea and formulate responses in meetings, utilizing open-ended discussion opportunities, and avoiding distraction. Many of these techniques are commonly encouraged in creative visual art, design, music and performance industries, yet have not been focused on natural scientists. Organizationally, the restructuring of infrastructure could provide space for creative exchange and offer opportunities for structured critiques; create common areas to allow for spontaneous conversation and promote shared space between colleagues who work on diverse issues, in an effort to promote discussion.
6. Within the arts, creativity—as we define it here—is valued and supported as critical to both the process and outcome of artistic production. In the natural sciences, creativity is not explicitly valued by scientific institutions and therefore not perceived as desirable by the scientist. Often, questioning the norm necessary to create new processes and products is seen as being detrimental to an institution, requiring risk-taking and courage (Scheffer et al., 2017; Segarra et al., 2018). The number of publications, their citations, and the prestige of a journal typically remain more important than the transformative process and outcome of the scientific product. Ideally all these metrics —as well as the ensuing uptake by industry or impact on society—should be a reflection of creativity, but it is not assessed or valued in and of itself. The scientific reward structure does not address this lack of recognition head-on. A change in attitude by the scientist will only be achieved through an incentive structure and value system that encourages transformative creativity above everything else. The extent to which a scientist makes associations across disparate areas of study, and the blending or merging of ideas, may serve as a starting point for developing metrics of creativity, possibly through the diversity of institutional affiliations of authors. The diversity of methods and experiments used to create new knowledge may also

manifest itself in longer scientific articles that develop a story rather than snapshot solutions.

It may turn out that creativity defies easy quantification in the natural sciences, as ideological, corporate and political circumstances challenge the unambiguous assessment of creativity of the scientific product. Valuing and incentivizing creativity in the natural sciences may mean supporting the mechanisms that we do recognize to enhance creativity, rather than by concentrating on learning creativity itself (Bohm, 1968).

Blending ideas may still require the solitude of traditional reading of the scientific literature, but unregulated interactions with colleagues and ensuing chance encounters may provide greater opportunities to foster a creative spark than meticulously planned research, for as much knowledge as the scientist may possess. Valuing creativity will certainly include many priorities that some institutions have already set for themselves, such as allowing increased physical proximity between disciplines that are targeted for collaboration. Yet key is to organize the incentive and support structure through the lens of how to promote creativity. When designing institutional structures, one may want to recognize that creativity is likely not the outcome of a universally applicable method that can be enforced but a highly individual path to be explored. From our own experience as artist and natural scientist, infusing lessons from artistic creativity into this planning process will enrich the outcome.

Promoting creativity in the natural sciences with artistic practice in mind

Many proposals have been made over the past decades about how to advance creativity for industrial and professional innovation that include institutional and individual methods (De Bono, 1973; Couger, 1996; Hemlin et al., 2004). Here we utilize the above-mentioned entry points that have emerged from an observation of artistic practice and briefly highlight three key organizational strategies that may promote individual and collective creativity in the natural sciences. The following strategies merely serve as an illustration of starting points from our point of view and of what is in some cases already practiced, and will require more space than is available here.

1. **Train** respectful critique; a "working memory" (Baddeley, 1992) to recognize chance discoveries; reaching a mental space of heightened perception; and a state of mind that is accepted or even expected of the artist, when in fact, the creative scientist is literally dreaming up new realities. Such training is a long-term educational process, of unlearning and learning, not a short-term instruction, and may involve starting from either observation or theory. Art practice, intent and question may then ignite new dimensions of thinking in the sciences (Bohm, 1969) and open up avenues for art-science instruction (Gurnon et al., 2013) also as part of integrated science-technology-engineering-arts-mathematics (STEAM) programs (Bequette and Bequette, 2012; Segarra et al., 2018).
2. **Organize** regular interactions between scientists to critique processes and results; and experiments to contain trial and error. An institutionalization of future-orientation as explored at the Center for Science and the Imagination of Arizona State University (Selin, 2015) builds on broad institutional support and individual engagement. These approaches also require an environment of trust to share insights and an environment of respect for creativity. A Co-Lab connecting artists and scientists may test assumptions about critique in unexpected ways, and may promote needed risk-taking (Segarra et al., 2018). The arts may be particularly effective partners for deep collaboration by providing "trading zones" that are divorced from disciplinary constraints (Brown and Tepper, 2012).
3. **Build** common and individual spaces that promote chance encounters across disciplines and with non-academic sectors, and that allow for the mental space to generate the creative spark. Few of these suggestions are new in their respective fields, but little is applied in academic education (DeHaan, 2011) or practice in the natural sciences.

Finally, to leverage insight from artistic creative practice it will be necessary to depart from considering natural science as the antithesis of art, and to recognize that art and science share many basic requirements and techniques that promote creativity. We urge academic institutions and individual scientists to take on this debate with the sincerity that it requires.

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Additional information

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