Creativity in research – current perspectives on the nature of, the conditions for, and role of creativity in research

Research note

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1.0 Creativity in research

Creativity can be seen as a vital component of scientific endeavour. In order to move science forward, scientists need to be creative and innovative, to take risks and to move beyond established knowledge and paradigms. However, with the acceleration of the scientific system, some have begun to raise concerns about the possibilities and incentives for innovation and creativity in modern day science. Marcus Baer and colleagues argue that "the conditions that allow and encourage scientists to engage in the relentless, creative exploration of the unknown are becoming harder and harder to find" (Baer et al., 2023), and Foster et al. are equally pessimistic: "High-risk innovation strategies are rare and reflect a growing focus on established knowledge. An innovative publication is more likely to achieve high impact than a conservative one, but the additional reward does not compensate for the risk of failing to publish" (Foster et al., 2015).

There is, in this way, a fear that scientists and the science systems are become less creative, less able to sort through the ever-expanding mountain of publications to find those truly innovative ideas and less willing to risk failure due to heightened competition, and calls have begun to emerge for the scientific community to strengthen and support creative environments.

Creativity is, however, difficult to define, let alone measure as a single concept. It has conceptual overlap with a number of related terms, such as innovation, novelty, interdisciplinarity, disruption etc, and in this research note, we take creativity as an umbrella term, where all of these related concepts are seen as components of creativity. This is partly due to the conceptualizations and operationalisation in the studied literature, where e.g. novelty or interdisciplinarity is often used as indicators creativity.

To make matters more complex, creativity has both an individual component (creative persons), a process side (creative processes or environments), as well as a "material" or output side (creative products). In the following research note, we focus on the processes and the material side, meaning that research on creative individuals, or the potential connections between personality traits and creativity are excluded to make room for an overview of the processes wherein creativity arises, and the products that emerge. To this end we have identified a set of key publications (through literature searches in main databases, and prior knowledge of the field). These publications were then used as reference points, meaning that we searched their reference lists and incoming citations, to discover additional literature, whose references lists and incoming citations were then also explored and so on (a method known as snowballing).

Below we first describe how creativity has been conceptualized and operationalized, i.e., what creativity means in the context of research and how it can be measured. Second, we describe the causes of creativity, i.e., what conditions foster creativity in research. Third, we describe the consequences of creativity or how creativity connects to research excellence and impact.

1.1/ The nature of creativity in research

As mentioned above, definitions of creativity in research often distinguish between creative products, processes, and persons (Stumpf 1995; Lee et al., 2015, p. 685). Heinze et al. (2007) elegantly describe the myriad of related terms and connotations of creativity, by stating that:

> *"There are a number of other related terms and concepts that make up the cognitive conceptual space in which creativity is embedded. These include talent, thinking, insight, imagination, inspiration, ingenuity, innovation, intelligence, inventive, virtuosity, excellence, learning, discovery, experimentation, risk-taking, and avantgarde. Some of these analogous terms refer to the creative product, such as an insight or a discovery. Others point to aspects of the creative process, such as experimentation or risk taking, in the course of which novel and unexpected outcomes are incorporated into an existing stock of knowledge and know-how via learning or socialization. Again other terms mention individual traits necessary to engage in creative activities, such as imagination, intelligence and talent"*

In the following we attempt to disentangle this by first addressing the creative product, since these are normally the object of measurement, and thereby the visible and countable item of creativity. Subsequently we unfold the knowledge on creative processes, before we move on to highlight what we know about the conditions for both.

1.1.1/ Creative products

Much of the empirical literature discovered in this note has focused on creative products. The definition of creative research products often involves two components: 'novelty' and 'usefulness'. For example, Heinze et al. (2009) defines creativity as "knowledge and capabilities that are new, original, surprising, and useful", Baer et al. (2023) defines creativity as "the generation of ideas that are new and have potential value by addressing a problem or capitalizing on an opportunity", and Ochse (1990 p. 2, cited in Stumpf 1995) defines the creative product as "original (new, unusual, novel, unexpected) and also valuable (useful, good, adaptive)".

1.1.1.1/ Bibliometric operationalization and methodologic issues

Most empirical studies investigating causes and consequences of creative research products use bibliometric indicators, which are meant to capture the 'novelty', 'originality' or 'disruption' of research. Thereby, the 'usefulness' component of creative research products is not captured in these studies, which should be noted going forward. Overall, the studied literature uses two approaches to measure creativity in research, which we critically review below.

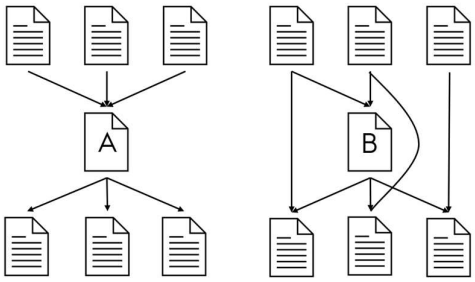
In the combinatorial approach, novelty is operationalized as unusual combinations of journals in reference lists. That is, if a publication cites journals, which are rarely (Uzzi et al., 2013) or never (Wang et al., 2017) found in the same reference list, this indicates that the publication is novel.[1] A study by Bornmann et al. (2019) found some convergent validity in using rarity of journal-combinations in reference, i.e., it correlates with experts assessments of novelty, but found no convergent validity in using uniqueness (journal-combinations which have never been made). A problem with the combinatorial approach is that it makes it difficult to empirically distinguish between novelty and interdisciplinary research, since the interdisciplinarity of a publication is also often measured using the distance between journals in its reference list (Porter & Rafols, 2009). Fontana et al. (2020) summarizes how this is a problem:

> *"Interdisciplinary research is believed to foster novelty (D'Este et al., 2019) and therefore some correlation is expected between the two measures. However, measures of novelty and interdisciplinarity should capture different properties of scientific discovery, since interdisciplinary research is not necessarily new, and new research is not necessarily interdisciplinary."*

[1] Another type of combinatorial approach is the unusual combinations of keywords (Boudreau et al., 2016; Foster et al., 2015), however, this approach is not as often applied as the journal-based.

The other approach to measure creativity is the citation network-based approach (Shibayama & Wang, 2020; Wu et al., 2019). In this approach, the originality or disruptiveness of a focal publication is determined by the relative shares of publications which 1) cite both the focal publication and its references, 2) only cite the focal publication, and 3) only cite the references of the focal publication. A publication is viewed as more original/disruptive if many of its citing articles do not cite its references and if few publications cite its references, but not the focal publication itself. This is demonstrated visually in the figure below; here publication A is original/disruptive, whereas publications B is not.

Figure 1: A 'disruptive' (A) and 'non-disruptive' (B) publication. Arrows indicate direct citations.



A recent paper by Park et al. (2023) gained widespread attention by using the approach to claim that papers and patents are becoming less disruptive over time. While some variations of the disruption index show some convergent validity, i.e., correlate with expert assessment of disruptive publications, there are many methodological issues with the approach (Leibel & Bornmann, 2024).

For example, contrary to what should be expected, increasing the number of publications, which do not cite the focal publication but cites 1 or more of its references can *increase* the disruption score of the focal paper (see ibid., p. 616 for a numerical example).

1.1.2/ Creative processes in research

Turning now to the *process* of creativity, the literature seems to discuss several characteristics of creative processes in research, but fewer empirical investigations of these processes. Creative processes in research have been the object of study for many years and some of the seminal works highlight a number of factors, that are seen to be important in creative processes, e.g. the absence of serious threat, willingness to take risks, emotional awareness, openness and confidence (Torrance, 2018).

In his review on creativity in research and development environments, Burbiel (2009) suggests that there are two models or theories of creativity – the componential theory and the sequential models. The componential (Amabile, 2018; Amabile et al., 1996) is based on an individual view on creativity and highlights expertise, creative-thinking skills and motivation. The sequential models are more process oriented, and specifies phases of the creative process, i.e. "the four stages in the development of an idea are: preparation, incubation, illumination, and verification" (Burbiel 2009, referencing Holm-Hadulla (2005); Scott (1995); Wallas (1926))

Burbiel (2009) condenses these phases and defines creativity as *a process of idea generation and idea validation*, highlighting that novelty of ideas is not necessarily sufficient, if one wants to study creativity in research. The idea generation phase requires divergent thinking skills, whereas the idea validation phase relies on convergent thinking skills to be able to assess the usefulness of the ideas generated. Burbiel also reviews literature on some of the techniques that can be used to foster and support these phases of creativity, and e.g. highlights research on brainstorming in research groups, which suggests that this widespread technique is not necessarily the best choice for large groups, as: "felt creativity is higher if brainstorming is performed in a group with n members, the measurable outcome is higher if creative tasks are performed by n individuals and ideas are then pooled ("nominal group")" (Burbiel 2009, with reference to Nijstad and Stroebe (2006)). This effect is described as *production blocking*. Other creativity techniques that are seen to have better effects are "externalisation" techniques, aimed at e.g. externalizing tacit knowledge in groups.

1.2/ Conditions for creativity in research

The second question posed in this research note is what the optimal conditions for creativity in research are – both in terms of process and product. Before the insights from the literature on this question, however, two methodological caveats should be mentioned. First, the literature relies on indicators of creativity which are problematic in many ways (see section 1.1.1.1). Secondly, the literature uses observational data, meaning that the validity of their causal claims is low compared to (quasi) experimental designs, i.e., from the studies we cannot be sure that e.g. team size *causes* variation in creativity. With these caveats in mind, we present the themes which is seen to be valuable in terms of fostering and nurturing creativity in research environments.

1.2.1/ Funding

One of the themes that has been studied as a factor in relation to creativity in research is funding, and particularly competitive funding. Wang et al. (2018) find that competitive funding leads to *less* novel research among junior researchers when compared to institutional funding. Their explanation is that "...peer-review in competitive project selection procedures is biased against novel proposals" (ibid., p. 1072), and that stable funding provides autonomy and removes the pressure of delivering what was promised in project proposals. They do not find that competitive funding leads to less novelty among senior researchers, which they explain by stating that "...reviewers tend to tolerate unorthodox ideas proposed by applicants with more prestigious academic background or more impressive performance records" (ibid.).

The statement that peer review should be biased against novel research is corroborated by Boudreau et al. (2016). They measure novelty as the proportion of Medical Subject Headings (MeSH; a keyword system in the life sciences) in a project proposal which are new and find that reviewers gives lower scores to novel proposals. However, Teplitskiy et al. (2022) find that novelty measured as unusual combinations of journal in reference lists is associated with *higher* acceptance rates of manuscripts in life science and physics journals. From these two studies it is inconclusive whether peer review is biased against novel research.

Heinze et al. (2009) conducts case studies of research accomplishments in human genetics and nanotechnology which are nominated by peer scientists as being creative. Their methodology implies a lower generalizability, but a higher validity in measurement and causal claims compared to the bibliometric studies. They find that stable and flexible research funding which gives research leaders discretion in choosing projects, changing direction and allows for high risk/high gain research projects are conducive to creative research. This then speaks to the process perspective of creativity, by highlighting how stable and flexible funding may support the phases of creativity, and the research leaders' opportunities for supporting them.

1.2.2/ Team size

Lee et al. (2015) use the combinatorial approach to measure novelty and find that medium sized teams produce more creative research than small or large teams. Novelty increases as team size increase up to about 7 authors but decreases beyond that point. This is because skill diversity grows with team size but with diminishing returns (for example, adding authors from 3 to 5 increases diversity more than adding authors from 20 to 22), while larger teams also face communication and integration challenges. These opposite forces make 7 authors the optimal team size for creativity, according to Lee et al. (2015). In a similar study, Wu et al. (2019) use the citation-based approach and finds a continually negative effect of team size on disruption, i.e., smaller teams are more disruptive than medium sized teams. The difference in their findings is likely explained by different operationalizations. Uzzi et al. (2013) find that team size does not affect the median level of novelty in journal pairings in their reference lists. However, the most novel journal pairings within a paper (those in the 90th percentile) are more novel in papers writing by teams compared to papers by solo authors. They interpret this to mean that

author teams maintain a body of conventionality in their papers but include some highly novel elements.

Heinze et al. (2009) find that "...that research groups responsible for creative events often start with two people, the group leader and a PhD student or a post-doc. Later on, leaders deliberately limited their groups to no more than six to eight researchers" (ibid., p. 616); a finding similar to that of Lee et al. (2015). Their explanation is that small groups lead to non-hierarchical decision making and communication and allows research leaders to be more actively involved in research instead of spending time on administration. As mentioned above, the sequential models of creative processes support this by highlighting that large groups may be at risk of "production blocking" and thus forgetting novel ideas.

1.2.3/ Diversity (international networks, group characteristics, interdisciplinarity)

A third theme that emerges in the literature as a condition/factor which positively affects creativity is diversity. Diversity comes in many forms, and here the literature points to e.g. diversity in terms of gender, nationality, discipline and other types of variation within a research environment.

Heinze et al. (2009) find in their case-based study that research groups with a complementary variety of skills produce more creative research, echoing the findings of Lee et al. (2015). The complementary set of skills, however, can also exist at the level of the individual scientist, or come from communication or collaboration with external organizations. Hemlin et al. (2008) highlight that "Interdisciplinarity has often been found to be associated with creativity (e.g., Hollingsworth & Hollingsworth, 2000; Thagard, 2005), and disciplines have sometimes been seen as hindering creativity", thereby also supporting the argument made by Heinze et al (2009) and Lee et al. (2015). In a recent study, by Yang et al. (2022), it is also demonstrated that team diversity in terms of gender seems to enhance creativity both in terms of novelty and impact, measured as citation.

On the negative side, Wagner et al. (2011) find that international research collaborations tend to produce less novel research. Specifically, as the number of countries represented on the authors list increase, the novelty of the research decreases. They theorize that their finding can be explained by the transaction costs and communication barriers which international collaboration involves, which implies that the results do not cover collaboration between researchers from different nationalities working within the same research centre.

1.3/ The role of creativity - connecting creativity and excellence

As mentioned in the introduction to this research note, creativity is often assumed to be pivotal in research endeavours. But whether creativity *leads* to excellence in research is more difficult to ascertain, as the specific connection between creativity and performance/excellence is not straightforward – in part because both concepts are difficult to measure unequivocally and because the connection is not necessarily immediate in terms of time.

Uzzi et al. (2013) finds that the probability of being a highly cited paper is highest for papers, which have a solid base of conventionality, but adds some element of high novelty. Wang et al. (2017) finds that novel publications are more likely to be among the most cited in their field, and that their citation impact extends to more distant fields than non-novel publications. At the same time, they are also more likely to be among the least cited in their field. They interpret this variability in citations as indicating that novel publications have a high-risk/high-gain nature. Veugelers and Wang (2019) find that novel publications are more likely to lead to technological impact (measured as patent citations).

This highlights the problem we encounter when trying to assess and measure the role of creativity in research: our indicators for when we see creativity are not optimal - does novelty without impact/usefulness really indicate creativity, and how do measures of creativity differ from measures of interdisciplinarity? Overall, however, the studies do indicate that novelty could have some positive association citation impact, but exact nature of this association is still unknown given the current state of knowledge.

One specific form of creativity is perhaps worth mentioning here, namely the notion of serendipity. Serendipity as a concept is somewhat different from creativity as it is defined in this research note, as serendipity refers to the "chance" encounters of a solution to a scientific problem, either by finding a solution to a different problem than the one which was sought, or by stumbling on a solution in an otherwise undirected search (Yaqub, 2018). The two concepts, however, are often used together, and in his study of serendipity in science, Yaqub (2018) points to the many examples of "chance" discoveries, that have formed science and that to some extent can be seen as creativity, e.g. the accidental discovery of vulcanisation, through spilling a mixture of sulphur and rubber on a hot stove, or the development of chemotherapy from the discovery of a drop in white blood cells in soldiers after exposed to mustard gas (Meyers, 2007; Yaqub, 2018).

Yaqub – and other scholars who have explored serendipity and its preconditions – point to the role of chance, risk and utility in scientific excellence. Quoting Pasteur's description of Ørsted's discovery of electromagnetism, he points to the relationship between chance and excellence:

> *"Oersted held in his hands a piece of copper wire, joined by its extremities to the two poles of a Volta pile. On his table was a magnetised needle on its pivot and he saw (by chance you will say, but chance only favours the mind which is prepared) the needle move and take up a position quite different from the one assigned to it by terrestrial magnetism"*

Serendipity in this way is seen to have a close connection with "*the mind which is prepared*", thereby the skills of the researcher. In order for serendipity to occur, then, we need prepared minds, and the environments that are conducive to such events, i.e. environments where "controlled sloppiness" is allowed. Yaqub speculates whether the new emphasis on "efficiency, in combination with a shift towards funding at the project-level, might [..] make it harder to recognise and appreciate that it is possible for research to unexpectedly solve a later problem [...] where research may initially appear to have little utility and be deemed inefficient".

1.4/ Concluding remarks

In this research note, we have unfolded some of the main conceptualizations, antecedents as well as implications of creativity in research. To sum up, it seems clear that creativity – understood as the processes of generating novel and impactful ideas with the potential to change science – is seen as vital, even if it difficult to measure both the actual processes and the products. It is also clear from the studied literature, that there is a slightly pessimistic view on the present-day conditions for creativity and serendipity in research. It is beyond the scope of this research note to conclude whether this pessimism is justified but is does seem clear that if scientific environments are to stay creative, then there seems to be evidence that creativity in research can be supported in various ways, e.g. though stable and flexible funding, the right team size as well as through increasing diversity in research teams. Individual creativity required focus on motivation, creative skills and expertise – perhaps what Pasteur referred to as "a mind which is prepared" for chance discoveries.

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