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PERSPECTIVE

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Convergence science in the Anthropocene: Navigating the known and unknown

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Abstract

1. Rapidly changing ecological and social systems currently pose significant societal challenges. Navigating the complexity of social-ecological change requires approaches able to cope with, and potentially solve, both foreseen and unforeseen societal challenges.
2. The emergent field of convergence addresses the intricacies of such challenges, and is thus relevant to a broad range of interdisciplinary issues.
3. This paper suggests a way to conceptualize convergence research. It discusses how it relates to two major societal challenges (adaptation, transformation), and to the generation of policy-relevant science. It also points out limitations to the further development of convergence research.

KEYWORDS

adaptation, convergence, interdisciplinary science, resilience, societal change, sustainability, transformation

1 | INTRODUCTION

Rapidly changing ecological and social systems pose significant societal challenges on an increasingly populated planet. Navigating the complexity of these challenges requires individual knowledge domains to be united in multi- and transdisciplinary research. It also requires policy to be able to cope with, and potentially solve, both foreseen and as yet unforeseen societal challenges. The emergent field of convergence addresses the intricacies of these societal challenges. Convergence approaches are relevant to a broad spectrum of multidisciplinary issues. Examples include integration across human and natural systems for sustainable development and ecosystem health (Sachs et al., 2009), the integration of biosecurity, bioterrorism and science governance (McLeish & Nightingale, 2007), the promotion of interdisciplinary research in biomedical sciences (Sharp & Langer, 2011), the connection of science and environmental education (Wals, Brody, Dillon, & Stevenson, 2014), the utilization of concepts from quantum mechanics in technology development (Dowling & Milburn, 2003), and the application of games to education, transportation and business management (Kim, 2015).

The United States National Science Foundation (NSF) has highlighted the potential for convergence approaches to solve complex and wicked societal challenges. However, what exactly convergence approaches include, and what they are, remains poorly defined. Several definitions of convergence research have been forwarded with foci on technology, industry and business (e.g. Kim, 2015). The

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NSF provides a general, holistic definition: 'a means of solving vexing research problems, in particular, complex problems focusing on societal needs'. The NSF highlights two core attributes of convergence research: (a) the need to address a specific societal challenge or opportunity, and (b) the development of novel frameworks, paradigms and disciplines through interdisciplinary integration, often of seemingly loosely related, or orthogonal approaches. Guidance to make convergence research operational, while accounting for the advantages and limitation of such an approach, can be particularly important given the complexity and uncertainty of systems of people and nature that scientists and policy makers need to deal with (e.g. biodiversity loss, food security, terrorism, climate change, environmental degradation, resource overexploitation).

Here we suggest a way to conceptualize convergence research, while acknowledging that not all questions require a convergence approach. We set the stage by discussing two responses to fast societal change—adaptation and transformation—and discuss how convergence research can help with these responses. We conclude by highlighting the potential of convergence science to contribute to the generation of policy-relevant science and discuss implementation challenges.

2 | ADAPTATION AND TRANSFORMATION

Humanity faces two different but mutually nonexclusive ways of societal responses to change: adaptation and transformation. Adaptation aims to ensure continued human health and welfare while social–ecological systems undergo constant change. For instance adapting agriculture to maintain continued service (e.g. food) provisioning or its improvement (e.g. increased agricultural efficiency) in current times of fast social–ecological change are clear resilience management targets (Rist et al., 2014). Sustaining agricultural output in a changing world reflects the need for adapting these production systems to change, particularly to feed an increasing human population. However, in complex systems of people and nature, adaptation cannot be infinite because of the nature of the challenge and associated ecological and social constraints (Dow et al., 2013). Such constraints relate to a combination of rigid policy, limitations of currently available technological solutions and economic models embracing linear growth. Adaptation is often further complicated because the dynamic, uncertain, non-stationary environmental change is not accounted for in policy and management (Garmestani et al., 2019; Twidwell et al., 2019). In the absence of accounting for such constraints, adaptation can often become counterproductive or, according to Holling and Meffe (1996), 'pathological'. This means that management not only can have substantial environmental impact (water pollution due to agriculture) but more generally lead to the loss of resilience of the managed systems (Rist et al., 2014). The American Dust Bowl in the 1930s provides an example where a sole focus on adapting agriculture to satisfy human demands can have catastrophic outcomes. This brings us to the second form of societal change: transformation.

Transformation follows when adaptation to change is inadequate because the necessary social–ecological baselines are no longer aligned with management goals in a fast changing world. Adaptation is also counterintuitive and therefore undesirable in situations where costs substantially outweigh potential benefits in terms of the production of goods and services (e.g. commercial fishing in overfished marine environments). Deliberate transformation may therefore be required to deal with novelty arising from fast social–ecological change (Chaffin et al., 2016). However, the high uncertainty underlying the dynamics of systems of people and nature makes envisioning system transformations extremely challenging. This is due to a fundamental change in structures, functions, processes and feedbacks once a system has transformed (Angeler & Allen, 2016); for instance when coral reefs turn into algae dominated systems, when grasslands become replaced by forests or when democracies turn into dictatorships. In some cases, such as the examples provided, alternative system regimes have already come into being, and so are known. However, there are significant limitations in our ability to anticipate alternative regimes in many cases, as they may be novel, and therefore surprising. For instance the likelihood of the global climate shifting into a hothouse earth regime has been recently highlighted (Steffen et al., 2018). However, we can currently not envision, let alone define, when, for example the Arctic, which is especially vulnerable to change, or the entire Earth, may undergo a regime change once a climate change threshold has been passed. Or how long it will take to stabilize in the hothouse earth regime. Or how this change may affect human civilizations across the world. Or, exactly what the new Arctic will be like.

Despite these limitations, there is still a need to confront and navigate such change, requiring scholars from different disciplines to converge in developing strategies to facilitate and foster transformation and adaptation to social–ecological change. However, defining and operationalizing unknowns comprises a 'contradiction in absurdum' (Szent-Györgyi, 1972). Convergence approaches that build on and integrate the two complementary research traditions we introduce below can likely facilitate new discoveries and eventually address these 'absurd contradictions', thereby likely shedding new light on many challenges related to adaptation and transformation.

3 | TYPES OF CONVERGENCE

We distinguish between two interdependent convergence approaches, Apollonian and Dionysian science, that need to deal simultaneously with known and unknown problems that are inherent in adaptation and transformation challenges. The Apollonian–Dionysian comparison is rooted in Greek mythology and has found application in different realms of inquiry (science, philosophy, visual and performing arts) (Szent-Györgyi, 1972). The concept is inspired by Apollo, the Greek god of the sun, and Dionysus, the god of the vine. Both gods are attributed with different traits. These traits are analogous to different approaches in scientific research that relate to the refinement of existing and the creation of novel knowledge and potentially new disciplines and paradigms that can inform adaptation and transformation (Szent-Györgyi, 1972; Figure 1). There is a third concept of convergence, in the social sciences and biology, which focuses on the development and evolution of similar structures, processes and performances (Futuyama, 1986; Kerr, 1983). This focus on homogenization is distinctly different from the problem-solving goals in emerging interdisciplinary research that we target here, and will therefore not be further discussed.

Apollonian science tends to apply the scientific method and develops research meant to refine existing knowledge. Apollonian research envisions future lines of research and applies a goal-oriented, logical and structured questioning process about what we know that we do not know to fill existing knowledge gaps. Building on advances within problem-based approaches to science and policy, and following the intellectual tradition of sustainability studies that have asked similar sets of questions for defining sustainability in any particular context, our first type of convergence can therefore be conceptualized as 'convergence of what, to what and for whom' (Carpenter, Walker, Anderies, & Abel, 2001). This form of convergence, *Apollonian convergence*, brings together two key terms in this paper: Apollonian and convergence. Operationalization is the major tenet of Apollonian convergence and reflects, per definition, the need to address or solve a scientific or societal problem; for instance securing clean biofuel production, improving environmental disaster management and technology such as quantum computing. This highlights the need to converge in a goal-oriented way to address and solve known problems through synthesis and interdisciplinary research. Imagine current challenges in a fast changing Arctic: Interdisciplinary collaborations between ecologists, hydrologists, engineers and climate modellers may develop management strategies to mitigate the mounting degradation of arctic rivers (of what) caused by changing climate (to what), thereby securing sustenance fisheries for native communities (for whom).

Because the 'of what, to what and for whom' can differ substantially among the plentitude of societal challenges humanity faces, and the differences in desired outcomes across societies, it is unlikely that a one-size-fits-all Apollonian convergence approach will be able to collectively address individual challenges, each with their own intrinsic properties. Apollonian convergence around the challenge of a rapidly changing Arctic may differ drastically from collaborations aiming to develop new statistics, thermodynamics and chemistry to explain the origins of life, or developing new computational tools and techniques to detect signals in clinical data (Sharp, 2014). These disparate and distinct examples show that approaches between individual-specific convergence collaborations is limited to a broad Apollonian framework only. However, convergence between individual yet related projects may provide fertile ground for addressing broader goals with higher complexity and uncertainty. Simultaneously addressing local food security for arctic communities and the sustainability of mid-latitude agricultural productivity resulting from arctic change provides an example of such goal-oriented convergence.

This example shows that we need to deal with societal problems that are overwhelmingly complex. In many cases this complexity is difficult to envision, identify and cope with before problems manifest, often persistently and irreversibly (e.g. slow climate-related regime shifts; Spanbauer et al., 2016). In such cases, no a priori solution can be identified for a challenge that is not manifested yet, which limits the implementation of sound adaptation or transformation strategies. It is therefore unclear what will converge to what, for what and for whom; that is convergence is not goal-oriented and cannot be a priori concretely operationalized. Activities to promote research into the unknown are, thus, guesses. However, it is under such circumstances that novel knowledge can be generated and increase our understanding of complex challenges. This brings us to a research approach that has historically been rooted in accidental scientific discoveries from which the foundations for alternative societal development can be laid.

Compared to Apollonian science, Dionysian research relies more on intuition and creativity to open new, unexpected alleys for discoveries. Dionysian discoveries are often independent of recognized scientific methods. They can be serendipitous and accidental and result from the interplay of preparation, opportunity and desire (Gaughan, 2010). Dionysian discoveries are often unexpected products that show up in the slow process of experimentation according to standard methods, as the discovery of Penicillin by Robert Fleming exemplifies. Similarly, Dionysian discovery can result from combinations of existing knowledge in hitherto unimaginable ways, such as when Albert Einstein found that his theory of general relativity is well aligned with the non-Euclidean geometry of the 19th century German mathematician Georg Riemann.

Dionysian discoveries have been made in many areas of scientific inquiry, for instance in the biomedical, natural and engineering sciences and the humanities and had lasting effects that transformed societies (Roberts, 1989; Table 1). This suggests that Dionysian inquiry, or *Dionysian convergence*, has strong potential to build the

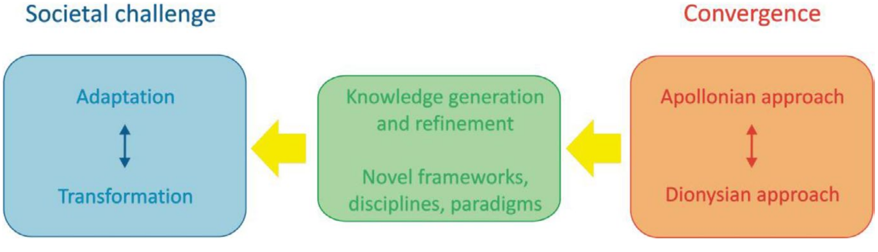

FIGURE 1 Apollonian and Dionysian convergence approaches to address societal challenges (adaptation, transformation) through the generation and refinement of knowledge and establishment of new disciplines, paradigms and frameworks

TABLE 1 Examples of accidental discoveries in science (based on Roberts, 1989)

Field	Discovery
Biomedical sciences	Antibiotics (penicillin, sulphonamides, magainins), drugs (aspirin, interferon, psychoactive compounds, LSD), others (insulin, antiallergenic and anticancer substances)
Material science	Teflon, polyethylene, nylon, safety glass, polycarbonates, Velcro, vulcanized rubber, Scotchgard, celluloid, rayon
Engineering and technology	Gasoline technology, microwave oven, electromagnetism
Chemistry	Hydroboration, alkene synthesis, oxygen, iodine, helium, noble gases, urea synthesis
Astronomy	Big bang, pulsars, Pluto's moon Charon
Physics	Newton's gravity, X-ray, nuclear fission, radioactivity
Food science	Corn and wheat flakes, Saccharine, Aspartame, Quinine
Life science	DNA
Archaeology	Rosetta Stone, ruins of Pompeii
Geography	Discovery of America

foundation for new paradigms or disciplines, which is a core element in NSF's definition of convergence research, to further develop and transform societies and provide them with new adaptation potential to cope with change. New paradigms and disciplines may not only generate new knowledge but also inform Apollonian science to recalibrate and refine goal-oriented problem solving (Figure 1). Apollonian and Dionysian approaches are therefore complementary in their ability to advance science. They may find, individually and together, application in convergence research for informing adaptive and transformative approaches to change and solving sustainability challenges (Figure 1).

4 | OUTLOOK

Recognizing the importance for the creative exploration of complex challenges, the NSF is now funding convergence initiatives (e.g. Converging to a New Arctic; Cross-Scale Processes Impacting Biodiversity) that are based on the Dionysian convergence idea presented in this paper. Such approaches may eventually address Szent-Györgyi's contradiction absurdity by facilitating and increasing the likelihood of Dionysian discovery. We discuss factors that may be relevant for funding and structuring Dionysian convergence. We also highlight challenges associated with the implementation of this approach.

Funding and structuring of convergence research with a Dionysian focus could be developed around psychological factors and working environments that facilitate creativity and collaborative learning and problem solving. There is potentially a plethora of factors that can inform Dionysian convergence to further the likelihood of discovery. An exhaustive description of these factors is beyond the scope of this paper but we highlight a few that can be especially fruitful for idea generation, particularly in multidisciplinary collaborative environments including participants from academia and the private and public sector (Alves, Marques, Saur, & Marques, 2007). Targeted funding to promote such collaborations could create the foundations for novel networks that may lead to the development of new approaches (data, solutions, lexica and practices) to envision and prepare society for unanticipated challenges. To this end, funding initiatives can target the encouragement of intuitive, creative thinking and engagement by stimulating learning that pertains to the affective (emotion, feeling) and cognitive (thinking) psychological domains. Such learning is inherent in art-science approaches (Scheffer et al., 2015), which have allowed for novel creative examinations of sustainability challenges (Angeler, 2016; Angeler, Alvarez-Cobelas, & Sánchez-Carrillo, 2018). It is therefore likely that targeted funding of collaborations between practitioners and scholars of creative and scientific disciplines may lead to alternative and novel views that may facilitate Dionysian discovery.

Art-science approaches may also have potential to address pervasive uncertainties inherent in the scientific process, especially the Dionysian. That is scientific research builds upon both error and success and it is likely that Dionysian convergence will be risky and frequently unsuccessful according to present academic standards. A starting point for learning by error within a Dionysian convergence context can be the development of creative and intuitive scenarios of potential unknowns. Such approaches can be inspired by the visual arts in which abstract paintings are an unrealistic representation of reality, but which become through their existence a part of reality themselves. That is Dionysian convergence scenarios may be equally unrealistic and therefore not immediately feasible. However, refining such scenarios or creating alternative scenarios through the introduction of unplanned elements may lead to surprises that may ultimately help identify novel pathways towards a desirable future. Such scenarios may serve as a benchmark for decision making to help reduce the risk of worst-case outcomes resulting from change becoming real. That such a strategy is already pursued is shown by the French army, which is recruiting science fiction writers to help military strategists anticipate future threats to national security (The Telegraph, 2019). Building on the creativity associated with mental illness may offer further potential, not only because of cultural, scientific and artistic gains for society (e.g. Jamison, 1996), but also to successfully navigate and solve political crisis (Ghaemi, 2011).

This perspective argues that systematic funding of Dionysian convergence approaches is worthwhile by increasing the potential to creatively uncover knowledge that can lead to novel frameworks, paradigms and disciplines. The latter, we believe, may have strong potential to shape future national and international policy and inform governance, which will be crucial to catalyse the transformation of societies to more viable futures (Chaffin et al., 2016). This may have lasting beneficial consequences for human and natural systems, while increasing the ability of societies to adapt to complex challenges. However, several linked issues remain of which we identify three here:

First, because Dionysian discovery happens fortuitously, the challenge is not how to pursue such a pattern of discovery, but how to foster a fertile environment that celebrates intuition and creativity. The evidence and logical arguments in the paper point to a new vision of science policy that is currently not embraced by the NSF or other national and international funding agencies even as they call for convergence research. Despite the value of integrating psychiatry, the humanities and arts and potentially other areas of inquiry (e.g. religion and spirituality) into realms of scientific innovation for Dionysian convergence research, such approaches are currently not endorsed by funding agencies as intellectual disciplines worthy of funding under the science umbrella. This points to the need of substantial changes in current science policies for embracing Dionysian approaches in convergence research.

Second, there is ample evidence in the philosophy and history of science that novel ideas, theories and concepts, which Dionysian convergence science likely can generate, will be met with scepticism and potentially ignored by the conservative scientific mainstream. Paradigm shifts which ultimately result in the uptake and practical application of novel scientific knowledge can therefore be slow and span generations (Kuhn, 1996). Such delays not only limit the advance of science and its technological application per se; they are also incompatible with the current academic culture. Specifically, Apollonian science with its more methodical, within-framework style fits better with the current publish or perish culture, unlike the unpredictability of Dionysian science that may achieve breakthroughs only slowly. Dionysian convergence science to be successful therefore requires not only the personal engagement of scientists but also the establishment of appropriate academic and research structures and a change in academic culture to eliminate competitive disadvantages that may ensue from the perusal of Dionysian research.

On a related note, such structures should also account for the need to make aforementioned trial-end-error insights and negative results in science publicly available. The need for dissemination of such results is increasingly recognized by the research community, not only to economize research funding and learn from past failures (e.g. Weintraub, 2016), but also to curtail a growing scepticism regarding the integrity and relevance of science, especially in the face of reproducibility issues (e.g. Jarvis & Williams, 2016). The highly competitive environment for funding and career promotion still incites researchers to publish positive results as they are more likely to be considered and favourably assessed by editors and reviewers of field-specific top-journals, and once published, are more likely to get (highly) cited. Concomitantly, the competition for prestige and the financial survival of journals makes it still more attractive to publish positive findings (Joober, Schmitz, Annable, & Boksa, 2012). These factors are especially important for early career scientists who need to 'play the game' for developing their careers (Allen & Mehler, 2019). Convergence science needs to play a major role to address these issues and further develop initiatives that transform the current dissemination culture in academia. The emergence of publications with an exclusive focus on negative results (i.e. Journal of Negative Results) or a more inclusive scope to accommodate the distribution of unexpected, controversial and provocative results is promising for the transformation of the publishing landscape. So too is the rise of online repositories (e.g. Preprints.org, ArXiv.org) for pre-print publication and storage of data to improve reproducibility. However, such changes are likely not enough without substantially changing a research culture that is exclusively focused on high productivity in highly competitive environments. Ultimately, research culture is not only a matter of the system but also of the individuals that form and are shaped by the system. Unfortunately, scientists too often use science counterproductively to satisfy their personal and professional hedonism and strive for success (Holiday, 2017). But it is the ego that needs to serve science, not science the ego for cultural change in academia to be implemented. There is currently a rich emerging literature on how science can be better organized to navigate the challenges of transforming science. Convergence research has opportunities to engage in these developments. It will need to account for a holistic approach, potentially inspired by ideas of a quantum society (Zohar & Marshall, 1993), in which the public, governments, funders, institutions and scientists need to design future functional science policies based on open-minded, process-oriented and creative dialogues.

Last, and most importantly, funding is always significantly limited by governmental allocation of taxpayers' money for scientific research. Szent-Györgyi's (1972) lament, almost half century ago, about the academic financing system unduly favouring Apollonian over Dionysian research still echoes into the present. This problem is still latent in emerging convergence science in which projects are to a great extent operationalized, goal-oriented and geared towards adaptation to specific challenges (Kim, 2015). A further major challenge for convergence research in the future therefore is to find a balance between funding Apollonian and Dionysian approaches. Given funding limitations, financing of Dionysian science will likely come at the cost of funding of Apollonian research. Whether governments will likely allocate a significantly higher amount of their gross domestic product for the exclusive purpose of funding Dionysian convergence research remains at this stage elusive.

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CONFLICT OF INTEREST

The authors have no competing interests to declare.

AUTHORS' CONTRIBUTIONS

D.G.A. conceived the idea and wrote the paper; C.R.A. and A.C. contributed to idea development and the writing. All authors gave final approval for publication.

DATA AVAILABILITY STATEMENT

This study did not include any data.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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