Opportunities and Challenges for a Maturing Science of Consciousness

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The problem of consciousness – explaining how subjective experiences come about – is often portrayed as a deep mystery, requiring radical solutions such as the revision of fundamental physical laws. **Despite the ongoing controversy concerning the scope of the problem that consciousness poses to science at a conceptual level,** it has become increasingly clear that current empirical and theoretical work is already leading to valuable scientific and clinical insights. For this translational potential to be fully realized, factors essential for the growth of the discipline, such as funding and creation of jobs, are just as important as the empirical findings themselves. Here we discuss these issues and call for the recognition of consciousness science as an indispensable area of biomedical research.

What renders some cognitive or mental processes conscious, whereas others are not? **Are various non-human animals conscious, and, if not, why not?** Even within the same individual, different states of consciousness exist at different times, **yet consensus on a scientific theory of this phenomenon** has long remained elusive.

Although the problem of consciousness might seem abstract, the study of consciousness has many practical consequences. Achieving a better understanding of consciousness is critical to multiple medical, scientific, legal, and ethical issues, such as the detection of consciousness in anesthetized or non-communicating patients, infants, other animals, and machines [1,2]; epilepsy seizure classification; the measurement of well-being and happiness; and the assessment of moral responsibility [3].

In the early 1990s, the first academic society focused on consciousness research, the Association for the Scientific Study of Consciousness (ASSC), as well as multiple dedicated conferences and journals, were launched. Through the past couple of decades, approaches and methodological standards applied by consciousness researchers have rapidly risen in rigor and sophistication in line with other neuroscientific fields [4]. **Notably, the widespread adoption of rigorous experimental procedures using subjective reports, once eschewed by behaviorists as being outside the realm of science, has paved the way for new areas of scientific enquiry within neuroscience. Among others, these areas include the study of self-consciousness, metacognition, and mind-wandering. Despite methodological difficulties, attempts to acquire data about subjective experiences have helped move** theoretical debates **on consciousness** away from speculations based on personal authority towards testable empirical predictions [5].

Given this progress, exciting new potential for further growth has become possible. In particular, we believe that consciousness science can contribute to addressing a wide variety of clinical challenges. Whereas the relevance of consciousness for various *neurological* disorders **— such as the vegetative or minimally conscious states that may result from traumatic brain injuries —** is well recognized, more work can be done to highlight its potential for improving our understanding of *psychiatric* illnesses. For instance, consciousness research is not yet recognized as one of the strategically focused areas in NIMH's Research Domain Criteria (RDoC) (Supplementary Note 1). Nonetheless, subjective experiences are just as important as physiological symptoms in terms of treatment outcomes. An understanding of the mechanisms underlying such experiences may therefore guide us in finding the appropriate biological target for treatment and intervention.

This issue has recently come to the fore in the case of anxiety disorders, particularly in debates regarding whether targeting the amygdala may be the most effective strategy for reducing subjective fear [6]. It has been argued that effective treatments of anxiety and phobia require an understanding of the conscious experiences associated with these mental states, beyond their behavioural consequences [6,7]. Similarly, the focus of pain research has moved from understanding the mechanisms of noxious stimulation to understanding the mediators of subjective pain experience [8]. Several studies have also emphasized the role of consciousness science in explaining the symptoms of schizophrenia, as explicit and implicit cognitive processing seem differentially impaired in this condition [9]. **As such, translational applications of consciousness research have the potential to create a virtuous cycle, whereby a theoretical understanding of consciousness guides ever more successful clinical interventions, and clinical results, in turn, provide critical material to evaluate and refine empirical theories.**

Despite these exciting new translational applications of consciousness science, a relative scarcity of academic jobs and funding opportunities presents obstacles to further development. In recent years, many more employment openings have arisen in similarly 'young' neuroscientific disciplines, such as neuroeconomics and social neuroscience, than in consciousness research (Supplementary Note 2). We suspect that this may be related to the lack of funding opportunities: competitive institutions understandably do not want to create positions to be occupied by what may be perceived as unfundable science.

How bad is the funding situation for consciousness science? Amid a general shrinkage of research budgets in many countries, one might expect funding to be scarce. Overall, funding for consciousness research seems relatively healthy in Europe, with multiple sizable grants (e.g. from the European Research Council (ERC)) on par with those supporting other major topics in neuroscience. Between 2007 and 2017, 0.25% of all ERC grants were awarded to projects focused on the study of consciousness (Supplementary Note 3). Even in the US, despite the traditional perception that public funding mechanisms are conservative, some subfields of consciousness research have begun to gain recognition under public funding mechanisms — although the proportion of grants dedicated to the study of consciousness by the NIH between 2007 and 2017 is only one-tenth of the proportion of ERC grants for projects on the same subject (Supplementary Note 4). Specifically, studies of *states* of consciousness of individuals, including the neurological mechanisms distinguishing sleep from wakefulness, or being anesthetized from being in a coma, have attracted multiple major grants (R01s) from the NIH in recent years (Supplementary Note 5).

Nevertheless, some areas within the field may face more challenges than others. For example, there are many researchers who study the varying *contents* of consciousness within an awake individual, or the essential mechanisms distinguishing conscious from nonconscious processes during normal wakefulness, rather than the varying *states* of consciousness that occur during sleep or in medical conditions. One hurdle for these scientists is the common misconception that their topic of study is already covered by other areas of research, such as attention, memory, and perception. Yet, whereas many neighboring fields are relevant, empirical studies have shown that consciousness can be dissociated from many other cognitive processes [4,5]. Understanding the mechanisms underlying consciousness of specific *contents* therefore requires dedicated efforts. Finding public funding support for this

kind of work is not impossible, but seems to have been relatively challenging, at least in the US (Supplementary Note 4).

This is where private funding may provide crucial opportunities. Across disciplines, private funding is becoming increasingly relevant for high-risk, high-reward neuroscience projects. In addition to companies such as Neuralink and Facebook, some private foundations prioritize or focus solely on consciousness research (e.g., Templeton Foundation, Tiny Blue Dot Foundation, Mind Science Foundation, and the Azrieli Program in Brain, Mind, and Consciousness, hosted by the Canadian Institute for Advanced Research).

For the field to benefit effectively from these exciting opportunities, two specific issues are worthy of our attention. First, care should be taken to avoid over-emphasis on projects of unrealistic ambition, such as trying to unequivocally pin down a complete, universal theory of consciousness, beyond what can be tested empirically now or in the near future. **Whereas theories of consciousness are of utmost importance for driving further empirical progress, it is important to distinguish empirically productive hypotheses from mysterious and untestable claims such as, for example, the panpsychist view that an inactive set of logic gates could be conscious. Such hypotheses** might be tempting given the intriguing nature of the problem we are facing. Arguably, these projects may also have intellectual merits in their own rights**, and we recognize that claims initially perceived as being far-fetched could possibly end up being plausible**. But with limited **funding** resources, we should be careful about priorities. **Contrary to untestable speculations, evaluating theories of consciousness partly in terms of their translational applications could both lead to a more rigorous and empirically-grounded science of consciousness, and contribute to laying** the groundwork for broader support from public funding.

Second, if consciousness science is to benefit from private funding opportunities, it will need to address how peer review of proposed research can be implemented in an open and fair manner. An inclusive process of peer review by experts remains an essential method for enabling academic work of the highest standard, as opposed to an exclusive process of recommendations based on arbitrary personal contacts. Given the relatively small size of the field of consciousness research, the challenge lies in helping private funders identify unconflicted dedicated experts who are genuinely invested and broadly representative of the state of the art.

These issues are relevant for many other disciplines, but they might be particularly important for consciousness research in part due to how it is portrayed in the popular media. Although media exposure of consciousness science is frequent due to high public interest, popular articles often focus more on the theoretically far-reaching nature of the problem than on factual details of current empirical research. While this exciting image has served to increase public interest, it may not necessarily reflect the reality that theories of consciousness need to be tested rigorously, and revised amid the long process of accumulation of empirical evidence. We need to make sure that scientific breakthroughs in the field are adequately communicated to other disciplines, as well as to the public. At the same time, myths and speculative conjectures also need to be identified as such. Without addressing these issues, precious scientific funding may be misdirected, and the field may miss a unique opportunity to become an established discipline.

Many of the observations made above are in concordance with the results of an informal online survey, **in which respondents – academics both from within and from outside consciousness science – were asked for their views on the current state of the field, including questions on funding, the job market, the rigor of consciousness science, media impact, as well as how different theories may be received by experts and non-experts** [10]. While this survey may reflect some inevitable sampling biases, **we believe that its results are plausible, in part because they also align with the experiences of the present group of authors, most of whom are currently active researchers in the field**.

Despite these challenges, we remain optimistic about the future. **Although the views presented here should not be mistaken for a complete consensus within the field, it is the first time that so** many co-authors, including philosophers, psychologists, neuroscientists, physicians, and computer scientists, with active research programs tackling different aspects of consciousness science**, have come together for a common statement on the challenges they face as a scientific field**. Although many young academics are undeterred by these challenges, **the field could make further progress if more of them had the opportunity to make consciousness their primary line of research, instead of feeling compelled to switch to more fundable areas**. As consciousness scientists, we are privileged to study one of the most fundamental aspects of the mind — that which makes us who we are. Going forward, we encourage dialogue with funding agencies – both private and public, as we recognize the unique and irreplaceable contributions they each bring for both the immediate and long-term development of the field. In doing so, we are confident that the science of consciousness will emerge as a driving force not only to tackle a great scientific frontier but also to develop the science of subjective experience that we so urgently need to effectively address disorders of mental health.

References

1. Owen, A. M. *et al.* Detecting Awareness in the Vegetative State. *Science,* **313**(5792), 1402-1402 (2006).

2. Dehaene, S., Lau, H., & Kouider, S. What is consciousness, and could machines have it? *Science*, **358**(6362), 486-492 (2017).

3. Levy, N. *Consciousness and Moral Responsibility*. Oxford: Oxford University Press (2014).

4. Block, N. *et al.* Consciousness science: Real progress and lingering misconceptions. *Trends Cogn. Sci.,* **18**(11), 556-557 (2014).

5. Lau, H., & Rosenthal, D. Empirical support for higher-order theories of conscious awareness. *Trends Cogn. Sci.*, **15**(8), 365–373 (2011).

6. Ledoux, J. E., & Pine, D. S. Using Neuroscience to Help Understand Fear and Anxiety: A Two-System Framework. *Am J Psychiatry,* **173**(11), 1083-1093 (2016).

7. Taschereau-Dumouchel, V. *et al.* Towards an unconscious neural reinforcement intervention for common fears. *Proc. Natl. Acad. Sci.* (2018).

8. Woo, C. W., Schmidt, L., Krishnan, A., Jepma, M., Roy, M., Lindquist, M. A., Atlas, L. Y., Wager, T. D. Quantifying cerebral contributions to pain beyond nociception. *Nat. Commun*. (2017).

9. Berkovitch, L., Del Cul, A., Maheu, M., & Dehaene, S. Impaired conscious access and abnormal attentional amplification in schizophrenia. *NeuroImage Clin.*, *18*, 835–848 (2018).

10. Michel, M., Fleming, S. M., Lau, H., Lee, A. L. F., Martinez-Conde, S., Passingham, R. E., Peters, M. A. K., Rahnev, D., Sergent, S., Liu, K. An informal internet survey on the current state of Consciousness Science. *Front. Psychol.*, *9*, 2134 (2018).

Supplementary Notes:

https://www.dropbox.com/s/kc1shsqg6y4egwf/Supplementary%20Notes%20-%20Opportunities%20and%20Challenges.pdf?dl=0

Author contributions

The manuscript was written primarily by M.M., H.L, and S.M.F., after taking into account multiple rounds of comments from all co-authors, who also jointly approved the final version of the manuscript. Except for first author M.M., authorship list is in alphabetical order.

Competing interests

The authors declare no competing interests.