Institution: University of Sussex		
Unit of Assessment: 11 – Computer Science and Informatics		
Title of case study: Inspiring new understanding and engagement with the Science of Consciousness		
Period when the underpinning research was undertaken: 01/01/2006 – 31/12/2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Anil K. Seth	Professor of Cognitive and Computational Neuroscience	2006 - Present
Daniel Bor	Postdoctoral Research Fellow	2010 - 2013
David Schwartzman	Postdoctoral Research Fellow	2011 - Present
Keisuke Suzuki	Postdoctoral Research Fellow	2011 - Present
Warrick Roseboom	Lecturer in Cognitive Science	2015 - Present
Period when the claimed impact occurred: 01/08/2013 – 31/07/2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Public interest and understanding in neuroscience has been significantly enhanced as a result of Anil Seth's research in consciousness science. Tangible outcomes have been generated for a diverse range of stakeholders on a global scale: Internationally acclaimed new artworks directly informed by Seth's research have been created which have been seen by audiences of over 800,000 people across the globe since 2018; young people have been inspired to reconsider their assumptions about consciousness and to take up new career directions in response to Seth's work, and clinicians, wellbeing advisors and mental health service users have used his research to motivate new approaches in mental health. Broadcasters and film makers have directly drawn upon Seth's research to help them engage their audiences more effectively, citing his multi-disciplinary approach, and his ability to clearly explain complex material, as critical to engaging public interest and increasing understanding in this rapidly-evolving but still somewhat inaccessible scientific field. Seth's 2017 TED talk has drawn over 11 million views to date and has been cited by TED's CEO as one of the most significant additions to their science coverage, playing an important role in helping TED fulfil its core mission of spreading good ideas.

2. Underpinning research

Seth has pioneered multi-disciplinary research in consciousness science for nearly two decades. Since 2000 he has published >160 journal papers, has an *h*-index of 65, and in both 2019 and 2020 was recognised as a Web of Science 'highly-cited researcher' – recognising a sustained contribution over 10 years within the top 1% of researchers internationally. The impact of Seth's public engagement is substantially underpinned by his scientific work examining the neurocognitive basis of conscious perception and conscious selfhood. Seth is recognised for his seminal contributions to advancing scientific understanding of conscious perception as a kind of 'controlled hallucination' in which the brain's top-down predictions about the world (and the body) are reined in – 'controlled' – by bottom-up sensory signals. He has developed this framework in a rich variety of ways. In one example, he has authored an influential theory of 'perceptual presence' **[R1]** which explains why perceptual experience normally (but not always) has the quality of being 'real'. This account of perception clarifies why the colours associated with a condition called 'grapheme-colour synaesthesia' (in which letters elicit additional perceptions of colour) are not experienced as being part of the real world. Seth and his team have additionally shown how this form of synaesthesia can be acquired through intensive cognitive training **[R2]**, revealing a previously unknown potential for the plasticity ('changeability') of adult perceptual experience.

Seth and his team have also developed innovative virtual reality methods; for example, using deep neural networks to simulate biologically plausible and highly immersive 'hallucinatory' perceptual experiences **[R3].** This approach provides a new tool to explore why some clinical conditions are associated with distinctive visual hallucinations, and links machine learning to

cognitive neuroscience to shed light on the neural mechanisms that underlie both visual hallucinations and normal, everyday perceptual experience.
Seth's best-known research, however, lies in his influential theories of what it means to be a 'conscious self'. He has developed a much-cited model of experiences of emotion and of 'body ownership', based on predictive perception **[R4].** This research inspired innovative virtual reality experiments that have shown how basic aspects of conscious selfhood depend on predictive integration of signals arriving from both inside and outside the body **[R5].** Another pervasive aspect of the conscious self is the experience of the passage of time. Recently, Roseboom, Seth, and colleagues have developed an innovative 'clock-free' model of human time perception, which showed that subjective time perception is fundamentally related to changes in the content of awareness, substantially reframing scientific understanding of human time perception **[R6].**

Overall, Seth's research has exposed how conscious experiences are built from different kinds of perceptual predictions and, as such, directly scaffolds his public engagement activities. Seth's theories of perception and of self-awareness have shaped debates in areas including artificial intelligence and medicine (neurology and psychiatry), and have helped incorporate spiritual and contemplative traditions, including mindfulness, within a scientific outlook.

3. References to the research

[**R1**] **Seth, A. K**., (2014). A predictive processing theory of sensorimotor contingencies: Explaining the puzzle of perceptual presence and its absence in synesthesia. *Cogn Neurosci,*. 5(2), 97-118, doi: 10.1080/17588928.2013.877880 [236]

[**R2**] Rothen, N., **Schwartzman, D., Bor, D**. & **Seth, A.K**. (2018). Coordinated neural, behavioral, and phenomenological changes in perceptual plasticity through overtraining of synesthetic associations. *Neuropsychologia* 111, 151-162, doi: 10.1016/j.neuropsychologia.2018.01.030 [15]

[**R3**] **Suzuki, K., Roseboom, W., Schwartzman, D.J.** & **Seth, A.K**., (2017). A deep-dream virtual reality platform for studying altered perceptual phenomenology. *Scientific Reports* 7(1),15982, doi: 10.1038/s41598-017-16316-2 [24]

[**R4**] **Seth, A. K**., (2013). Interoceptive inference, emotion, and the embodied self. *Trends Cogn*. *Sci,* 17(11), 565-573, doi: 10.1016/j.tics.2013.09.007 [1006]

[**R5**] **Suzuki, K.,** Garfinkel, S.N., Critchley, H.D. & **Seth, A.K.,** (2013). Multisensory integration across exteroceptive and interoceptive domains modulates self-experience in the rubber-hand illusion. *Neuropsychologia,* 51(13), 2909-17 10.1016/j.neuropsychologia.2013.08.014 [290]

[**R6**] **Roseboom, W.,** Fountas, Z., Nikiforou, K., Bhowmik, D., Shanahan, M., & **Seth, A. K**. (2019). Activity in perceptual classification networks as a basis for human subjective time perception. *Nature Communications*, 10(1), 267, doi: 10.1038/s41467-018-08194-7 [20]

[Citations from Google Scholar 01/21; Seth's lab members in **bold**]

4. Details of the impact

Seth's research has made a significant contribution to enhancing public understanding of consciousness science, delivering tangible benefits for a broad and international community of audiences, educators, artists, students, broadcasters and practitioners. His work and engagement activity have demystified a subject previously considered arcane, resulting in millions more people now thinking about, and actively engaging with, the subject of consciousness science in new and creative ways.

Increased engagement and improved public understanding of consciousness science
A headline example of the extensive reach of Seth's impact is his main-stage TED talk "Your brain hallucinates your conscious reality" recorded in Vancouver, in 2017. The talk, which drew on his research (on perception as controlled hallucination) as a central narrative, was exceptional even by TED standards: it has >11 million views (30/01/21), was rated as one of the 14 most popular TED talks of 2017, features in TED's playlist of 10 most popular science talks and has been translated into 26 languages **[S1]**. David Biello, TED's science curator, describes Seth's TED talk as "the best neuroscience talk I've ever had the privilege to work on." He adds:

> "The hardest problem in neuroscience is explaining it in a way which is simple but scientifically accurate and also engaging. I can say that Anil's success in achieving this is reflected in the enormously high engagement with both the TED talk and his personal appearances for TED. His TED talk is among one of the most viewed in recent history and one of the most talked about TED talks for those who attended in person […] TED's relationship with Anil is ongoing and extremely beneficial to us." **[S2]**

Importantly, by engaging such a large audience with his research, Seth is also contributing to TED meeting its strategic objectives. Biello confirms:

> "Anil's work has helped us meet our mission at TED in two key ways… Firstly our motto at TED is "Ideas worth spreading" and I would say Anil's original approach to consciousness is one of those ideas worth spreading… Secondly, my goal as TED science curator is to demystify science or reduce the barriers so people are less intimidated by science and are less dismissive of their ability to grasp truly scientific concepts. I think Anil hits the marks on both those fronts for us, which explains why his talk is so popular".

Chris Anderson, TED CEO, further underlines Seth's impact:

> "Over the years, we've invited many speakers to seek to address the mystery of consciousness. Anil Seth's talk - and follow on podcast - may be the best contributions we've ever had on this topic." **[S2]**

Selected comments (out of >13k: 30/01/21) beneath YouTube's presentation of Seth's TED talk, indicate the extent to which viewers are inspired by his ideas, prompting them to engage in debate and think differently. Key topics for lengthier debate were drugs and mental health, and memorable statements within the talk: "I really connected with what he was saying […] Highly recommended; Wow! This changes everything! […]; One of the best Ted talks I've seen; Actually I now wish to study neuroscience." **[S3]**

Enhanced broadcast/media coverage of consciousness science

Broadcasters have reported increased capacity to engage their audiences in the subject of neuroscience as a result of Seth's research and outreach. According to BBC science correspondent Adam Rutherford, Seth's clarity and accessibility in being able to convey his research to lay audiences make him an invaluable resource for science broadcasters. Rutherford regularly uses Seth as a contributor on the BBC Radio 4 programme *Inside Science,* which typically has ~1.7 million listeners, including around 100K downloads per episode:

> "Anil Seth is my go-to person for anything relating to artificial intelligence or cognitive neuroscience. Until recently, dealing with the nature of consciousness has been the preserve of philosophy, and Anil is one of a few people to investigate this subject from a cognitive psychology and neuroscience point of view. This is one of the reasons why we at the BBC return to him repeatedly... because we know we will get a clear discussion of complex ideas that our audiences will understand." **[S4]**

This view is confirmed by Oscar-nominated, Emmy-award-winning film maker, Lucy Walker, who has used Seth as a key scientific advisor in a major upcoming 4-part Netflix series on the nature of psychedelics, where Seth's research expertise is helping Walker to fulfil a public education remit within a popular documentary format:

> "We felt the audience could understand these really challenging concepts if Anil were guiding them through these complex ideas. He is a really good explainer in this particular field of neuroscience and we researched lots of different people. In fact there is no-one else we are speaking to in this capacity anywhere else in the world." **[S5]**

Walker is clear that it is not solely Seth's presentation and accessible manner which makes him such an important contributor, but also the significance of his underpinning research, which is changing scientific understanding of the nature of consciousness:

> "The nature of our project is very much about public education and science education, and it's very challenging do this in documentary form because you have to get crafty about how you do public awareness and public education in a way which is exciting enough that people tune into a TV series in their millions. Anil's research is really at the forefront of this revolution of ideas […] and so you need someone like Anil who straddles all these fields to be able to illuminate these concepts for us." **[S5]**

Shaping artistic practice through consciousness science

The multi-disciplinary nature of Seth's research into consciousness has directly inspired new generations of artists to think and respond artistically in new and creative ways. This is exemplified by Refik Anadol**,** a US-based Turkish media artist who was awarded The Lorenzo il Magnifico Lifetime Achievement Award for New Media and Installation Art in 2019, and was chosen to be a featured artist opening the Venice Biennale in 2020. Anadol describes his recent work in VR as being fundamentally grounded in Seth's research:

> "Anil Seth's hallucination concept or consciousness concept was very inspiring to me when I was thinking about machine learning algorithms… I found his research to be an essential support to these speculations… In particular I was inspired by Anil's research in my project called *Machine Hallucination* in which I'm exploring synaesthetic architecture." **[S6]**

Machine Hallucination was a large-scale immersive work by Anadol which used the largest data set ever gathered for an artwork, in which machine learning algorithms processed over 100 million publicly-available photographs of New York City **[S6]**. *Machine Hallucination* showed at ARTECHOUSE in New York and had 110,000 visitors between Sept 2019 and Feb 2020. The resonance of Seth's ideas to new forms of architecture is also highlighted by Neil Leach, a British architect and Visiting Professor at Harvard. Leach says: "Anil's work has completely transformed my thinking. I have recently completed the manuscript of a book, *Architecture in the Age of AI*, and have dedicated a whole chapter to AI and Neuroscience, drawing heavily on Anil's ideas. I also show my students Anil's TED talk each semester." **[S7]**

New exhibitions, theatre and music have also been created as a result of Seth's research. For example, Seth was the primary science advisor to the year-long exhibition*, States of Mind: Tracing the Edges of Consciousness* at the Wellcome Collection in London (Oct 2015 - Oct 2016). The exhibition, which included a synaesthesia-training exhibit directly based on his research, attracted >264,000 visitors, with print highlights, feature pieces and reviews of *States of Mind* being circulated in most major national newspapers and science magazines, together reaching an estimated 7 million readers (Wellcome Trust estimate**) [S8].** As part of his Wellcome Trust Engagement Fellowship, he collaborated with award-winning US-based educational rap specialist, Baba Brinkman, on *The Rap Guide to Consciousness* (2017). This show was directly inspired by Seth's research on predictive perception, dating from a talk he gave in Tucson in 2016 **[S9].** Brinkman describes how the show brought specific themes from Seth's research to completely new audiences*:*

> "I found the field of "predictive processing" particularly well-suited to theatre and music, and as a narrative device that you can use in live performance, because of their experiential engagement…. Anil's research ended up being highly integrated into *The Rap Guide to Consciousness*." **[S9]**

About 8,000 people over 2 years have seen *The Rap Guide to Consciousness* live, including 85 live performances 'off Broadway' in New York **[S9]**. "Every single night had a Q&A so that's a lot of people learning about and being exposed to the ideas of neuroscience who might not have been otherwise." **[S9]** Brinkman also notes that his own artistic practice has been changed as result of engaging with Seth's work: "the things I have learnt from Anil Seth have caused me to rethink my entire artistic practice… Incorporating predictive processing theory has given me a whole new vocabulary about how a performance works, and how I interact with and perceive my audience." **[S9]** Videoed audience interviews collected from some of the 4700 people who bought tickets for Brinkman's show in New York feature comments such as "world-changing", "enlightening" and "educational" indicating that the work has indeed been successful in stimulating public understanding and interest in the nature of consciousness **[S9].**

Inspiring young people and influencing their life choices

Young people aged 11-25 have been particularly inspired by Seth's research, as feedback questionnaires collected by his research group demonstrate. His multi-disciplinary approach has particularly resonated with this demographic, for example: "I was surprised to learn how many different areas of study (maths, philosophy and IT) are involved in neuroscience […]" **[S10]**. His use of creative and diverse techniques to conceptualise consciousness have demonstrably helped young people to develop an understanding of subjects that had previously seemed

obtuse: “His use of accessible concepts including optical illusions, visual illusion and synaesthesia helped me understand the ideas he was explaining…” **[S10]**. For many, this experience has been of life-changing significance, as a selection of extracts from feedback received from young people reveals: “learning about Anil’s research was probably one of the biggest events impacting the way I see the world in my early teenage years” … “It immediately changed how I perceived the world” **[S10]**. “Anil’s work inspired me to get into the field of neuroscience, which has now led me to a PhD in clinical psychology…” “(his work was) inspiring a change in direction towards research surrounding consciousness and its practical applications, particularly in treating mental health problems and the future of AI” **[S10].**

The success of Seth’s wide-reaching communication of the science of consciousness is reinforced by the response to his piece on predictive perception written for the online magazine, *KidSpirit.* A worldwide jury of children voted the article as the best of 2019; Seth’s award was voted for by 75 children aged 11-17 who form the *KidSpirit* editorial world – these children come from many different countries, and often from underprivileged backgrounds **[S11]**. Seth travelled to New York to accept the award and to spend a weekend mentoring these children. Elizabeth Hochman – founder and executive director of the KidSpirit online magazine and community – commented on the unprecedented impact this had on these young people:

> “How many of those kids from all over the world would have ever encountered some-one with Anil’s expertise? None of them I imagine. Especially when you consider the diverse backgrounds of the kids we work with. The kids that encountered Anil were blown away by his ideas … that has been life changing for these kids, I would say**” [S11]**.

Benefits to clinicians and mental health service users

Seth’s research on consciousness has also changed lives and altered clinical practice in areas of physical and mental wellbeing. Following his TED talk, respondents included representatives from the health sector and people struggling with dissociative disorders or bereavement. Selected responses indicate the effect on individuals’ mental health: “My perspective has been changed and I feel like in some way my healing has begun“ [**S3**]; “Anil’s work has also helped me to better understand and so better cope with Major Depressive Disorder. Understanding how my brain works has been fundamental to my mental health” **[S10].** Examples also encompass clinical practice: Michael Garrett, Head of Clinical Psychiatry at SUNY Downstate Medical Center, New York, has been using Seth’s TED talk as a clinical intervention with psychotic patients who are experiencing auditory hallucinations. The results have been so positive that Garrett is planning to expand this into a research project exploring the utility of an individualized “Seth demonstration” as part of the treatment of selected psychotic patients. **[S10]**

5. Sources to corroborate the impact

[S1] Selected screenshots from TED.com (date captured):
https://www.ted.com/talks/anil_seth_your_brain_hallucinates_your_conscious_reality (06/02/20)
https://www.ted.com/playlists/608/most_popular_ted_talks_of_2017 (06/02/20)
https://www.ted.com/playlists/181/the_most_popular_science_talks (30/01/21)
[S2] Impact testimonials from TED: David Biello, TED science curator (27/01/21) and Susan Zimmerman, Speaker Director TED with quote from Chris Anderson TED CEO (01/02/21)
[S3] Comments beneath Seth’s TED talk at https://www.youtube.com/watch?v=lyu7v7nWzfo
[S4] Impact testimonial from Adam Rutherford, BBC science correspondent (12/20)
[S5] Impact testimonial from Lucy Walker (11/20)
[S6] Impact testimonial from Refik Anadol (11/20)
[S7] Consented questionnaire by Neil Leach (02/21)
[S8] https://wellcomecollection.org/exhibitions/states-mind-tracing-edges-consciousness; *States of Mind* Press report (05/09/16) including quoted responses from *The Lancet* & The Observer.
[S9] Impact testimonial from Baba Brinkman (12/20) + email (01/20) + https://bababrinkman.com/shows (video reviews transcript available)
[S10] Selected questionnaires (4) + email correspondence from Garrett (02/21)
[S11] Impact testimonial from Elizabeth Hochmann, Director KidSpirit Inc. (12/20)