SCIENCE AND SOCIETY

Neuroculture

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Abstract | Neuroscience addresses questions that, if resolved, will reveal aspects of our individuality. Therefore neuroscientific knowledge is not solely constrained within laboratories, but readily captures the attention of the public at large. Ideas, concepts and images in neuroscience widely circulate in culture and are portrayed in literature, film, works of art, the mass media and commercial products, therefore shaping social values and consumer practices. The interaction between art and science offers an opportunity to make the scientific community and the public aware of the social and ethical implications of the scientific advances in neuroscience.

The rise and meaning of a 'neuroculture'

Despite the intricacy and complexity, its substance and technical details, neuroscience research engages the interest and curiosity of the general public. This is hardly surprising as neuroscience carries promises of revealing the underpinnings of our individuality, such as emotions, consciousness, the way we make decisions and our socio–psychological interactions. Advances in brain research, such as the discovery of mirror neurons, thought to be involved in imitation, the recognition of intentions and empathy, the neural correlates of moral choices or the molecules that consolidate or erase memories, strike us as remarkable not only as scientific developments *per se*, but also for their outreaching societal and cultural repercussions.

Since the 1990s, various domains of knowledge have acquired a 'neuro' dimension: branches of the social sciences and humanities with their own intrinsic set of consensus and interpretation have been epistemically re-assessed and surrendered to more reductionist approaches generated by the hype around neuroscience. We have observed the emergence of novel disciplines such as neuroeconomics, neurotheology and neuroeducation, whose investigations into various spheres of human enterprise are ultimately premised on the search for underlying neural correlates.

In general, we are witnessing the rise of a neuroculture (or neurocultures), in which neuroscience knowledge partakes in our daily lives, social practices and intellectual discourses[1-3]. For instance, the dissemination of neuroscience theories, the availability of psychotropic medications and the latest neurotechnologies, such as fMRI (functional magnetic resonance imaging), are influencing healthcare strategies and legal policies as well as ways in which individuals think of themselves, their bodies or their mental disorders[4]. For example, we relate aggressive and criminal behaviour to dysfunctional firing in the pre-frontal cortex, brain images are used as evidence in court, it has become common to consider depression and sadness as a serotonin imbalance and to refer to the release of endorphins when talking about the sensation of pleasure from the consumption of chocolate or sex.

As part of this transformation, ideas, images and concepts of neuroscience are increasingly assimilated into the cultural imagenary[1,5-7]. Here, we specifically describe how neuroscience is captured in the artistic and commercial creations circulating in the public domain. The range of neuroscientific ideas and concepts referred to in this paper include neuronal visualisation techniques, investigations into consciousness by brain imaging as well as techniques of brain intervention and psychopharmacological remedies.

Ian McEwan's novel 'Saturday'[8], films such as 'The Man With Two Brains'[9] or 'Eternal Sunshine of the Spotless Mind'[10] drug advertisements, such as the animated TV commercial for the antidepressant sertraline (Zoloft), or video games advocating brain training, can all be classified as products of neuroculture (TABLE 1). Neurocultural products symbolise the transfer of neuroscience's idioms from the laboratory to society and culture. They create and inspire narratives about current neuroscience research and about the crucial role of the brain in our lives.

Neurocultural products not only draw inspiration from the beauty and wonders of brain anatomy and mechanisms, but also have the power to critically address neuroscience findings, as well as their meaning and implications for society and thus, serve as an interface between neuroscience and its public perception. Artists in particular draw on publicly available references that illustrate, among other things, scientific images and the natural world. In neuroculture, such references specifically describe knowledge about the brain and mind. Hence neurocultural products become metaphors to describe and interpret neuroscience knowledge embedded in social values and competing cross-cultural norms within divergent societies.

In recent years, a new field of research branded neuroaesthetics has proposed that the conception, execution or appreciation of visual art follows the 'laws of the brain'[11,12,13,14]. In other words, it considers the subjective aspect of aesthetic experiences in the creation and appreciation of art works to be superimposed upon common and universal neural circuits. As opposed to neuroaesthetics, neuroculture is concerned with all forms of art (not only the visual arts) and does not seek to understand art neuroscientifically. It encapsulates social and cultural values that arise and evolve with our understanding of the nervous system. We regard the neuroaesthetics approach as another form of a neurocultural product, confirming the expansion of the remit of neuroscience into the previously separated realms of knowledge and scholarship.

Certainly, the circulation of concepts and theories about brain function and the mind in the public domain and their representation in artistic creations is not a recent phenomenon. However, because of the escalating attention, resources and hopes invested in the advancement of neuroscience, it is timely to document the current state of this cultural phenomenon, trace its origins and highlight its role in fostering reflections on the social and ethical implications of science. Here, we aim to make the neuroscience research community aware of the importance of a mutually beneficial dialogue between science and society, as explored through public culture and the arts.

Brainhood: brains as selves

Pertinent to neuroculture and underlying many of its relevant products is the notion of brainhood, or the regard of the brain as the primary bodily organ, which we need in order to assert our identities[7]. Unlike other organs in the body, the brain is regarded as irreplaceable in its function to confer personhood. This feature of 'being', rather than 'having', a brain is what defines human beings as cerebral subjects. As science historian Fernando Vidal put it, the idea of the cerebral subject is a pre-requisite not a corollary of neuroscientific investigation, and can be traced back to philosophies about personal identity postulated in the 17th century (for a historical outlook see Supplementary information S1 (box)).

Paralleling witty philosophical thought-experiments, fictional narratives of brain transplantations have appeared in countless examples, especially in film. Cinematographic material is an especially rich domain in which the recent cultural history of the 'cerebral subject' can be traced to productions from the 1930s and the B-grade science fiction movies of the 1950–1970s[15,16].

Such cinematographic productions tackle the problem of personal identity free of rationally based epistemic constraints and without the obligation of reaching defensible conclusions. In 'Donovan's Brain'[17], a brain extracted from a billionaire's body is kept alive and maintains the autonomy and features of his self. Steve Martin's hilarious and more recent comedy 'The Man With Two Brains'[9] also reflects the absurdity and fictional complications of brain transplantation.

The work of contemporary visual artists also associates the brain with identity. However, at the same time, it often challenges the notion of the cerebral subject by highlighting a human being's individuality and history, which cannot be reduced to a single organ. In 2003, with the aim of achieving immortality, conceptual artist Jonathon Keats put his brain, as well as its original thoughts, up for sale. To comply with the conventional rules of commercial markets, he registered his brain as a sculpture created by himself through the act of thinking. He then facilitated the sale by producing an exhibition and catalogue at the San Francisco Modernism Gallery. The artwork consists of MRI images of his brain activity as he thought about art, beauty, love and death[18].

In Helen Chadwick's Self-portrait (1991; FIG. 1), two hands cradle a brain, as an offering or devotional gesture that sanctions the organ as sacred and underlines its uniqueness. The artist's hands hold the brain on a silk tissue, whose folds suggest the convolutions of the gray matter. The image evokes the notion of brainhood and of the cerebral subject as the artist reflects upon her own individuality and history. The image tells us that an individual's identity cannot be reduced to the brain and that a complementary, more personal understanding of the self co-exists with a brain-centred interpretation.

Gene versus brain based accounts of self

The brain is not the only biological entity to have inspired art and to have influenced culture. With the publication of the Human Genome Project in 2000, a general reductionist enthusiasm heralded the gene and the genome as the remit for identity and personhood[19,20]. Double helices, chromosomes and genes became iconic images, controversially representing the essence of human beings[21,22]. For example, Marc Quinn's 'Sir John Sulston: A Genomic Portrait' (2001), a display of bacterial colonies grown from fragments of Sulston's DNA, symbolises the instructive power of the gene in embodying the subject.

If we compare differences and similarities between the genome and the brain as two instantiations of self-identity, we would argue that the brain is a more relevant metaphor representing the self[23]. First, on a quantitative measure of complexity the brain by far exceeds the genome. The human genome has fewer genes than initially anticipated. Its informational content is encoded as a combination of four nucleotides. RNA alternative splicing, expression

Table 1 | **Neurocultural products**

Art category	Product	Artist/Author
Film	Brainstorm Donovan's Brain The Man with Two Brains Eternal Sunshine of the Spotless Mind Prozac Nation	Wood, 1983 Feist, 1953 Reiner, 1983 Gondry, 2004 Skjoldbjaerg, 2001
Literature	Saturday Neuromancer The Corrections Prozac Diary	McEwan, 2005 Gibson, 1984 Franzen, 2001 Slater, 1999
Television	The Brain Advertisement for Zoloft	Kirkby, 2002 www.zoloft.com
Education and entertainment	BrainAge™	Nintendo
Visual arts	Magic Forest Self-portrait fMRI Butterfly Untitled Between a Thing and a Thought Lullaby Spring Cradle to the Grave You must get out more, Mrs. Jones	Andrew Carnie, 2002 Chadwick, 1991 Suzanne Anker, 2008 Daniel Margulies, Chris Sharp, 2008 Susan Aldworth, 2001 Damien Hirst, 2002 Susie Freeman, Liz Lee and David Critchley, 2006 Pharmacopoeia Art

Figure 1| **Helen Chadwick (1991) Self-portrait.** Reproduced with permission from the Leeds Museums and Galleries (Henry Moore Institute Archive).

of non-coding regions and other possibilities for gene modifications bring complexity to the genome. In addition, increasing evidence shows that genes undergo structural epigenetic changes that mark genomes with a distinctive history of their own. The different brain structures and functions equip this organ with a complexity that is not reducible to simple combinatorial rules. Second, the brain provides a dynamic material edifice for the repository of human identity due to its inherent singularity and uniqueness. The incessantly changing structure and synaptic organization of the brain is the result of a continuous interplay of external contingent socio–environmental stimuli (that may drive epigenetic events) and internal processes that result in unique neuronal networks[23]. However, even if a neuroscientific understanding of the self is currently prevailing in the public domain, it is not exclusive as neuroscience encompasses genetics, cell and molecular biology, psychiatry and cognitive and behavioural studies.

The water of the brain…

The exquisiteness of brain anatomy and other structures of the nervous system, particularly the intricate and complex forms of dendritic branching, have captivated visual imagination since their delineation by Ramon y Cajal[24]. In recent years, rapid advances in neuroimaging technologies have aimed to visualise cellular processes of developmental and functional significance in the living brain[25,26]. The brainbow system, a sophisticated transgenic technique, provided extraordinary pictures of neuronal circuitry, rivalling artistic representations[27,28]. Andrew Carnie's 'Magic Forest' (2002), evokes Cajal's technique and modern confocal microscopy to depict the changing organization of neurons in the growing brain as a landscape of memories (Supplementary information S2 (figure)).

Since the 1990s, brain imaging technologies, such as fMRI, have enabled to image brain activity in real time. Visual artists are fascinated with such technologies and the iconic power of its computer-generated imagery, which has been said to reflect how 'the water of the physical brain is turned into the wine of consciousness'[29].

In their 'Untitled' work (2008) Daniel Margulies and Chris Sharp make use of fMRI recordings to map brain activity in a subject who, after having ruminated upon a passage about knowledge and perception from Kant's 'Critique of Judgment' listens to Stravinsky's 'Rite of Spring'. Their video shows a cross-section of a brain with changing patterns of colours in the areas that light up during the experience. A copy of Kant's seminal text and headphones channelling Stravinsky are available to participants, who can identify and 'perform' along with the experiment.

The paradoxical mirroring nature of contemplating a brain in action is also eloquently captured by visual artist Susan Aldworth. In one of her diary entries, where she reflects on her experience with a neuroradiological investigation of her own brain because of a suspected haemorrhage, she writes: 'I still cannot escape the thought that I am seeing all this and thinking all this because of the very thing that I am looking at'. 'The brain is a very strange and marvellous thing. It is not like the heart or a kidney, it is thinking flesh'[30]. Aldworth is interested in theories of personhood and the phenomenon of consciousness. In her work 'Between a Thing and a Thought' (2001; FIG. 2a), Aldworth arranges in a wood and glass tri-panelled screen a series of drawn-upon brain scans. In this freestanding work she puts images of her own brain on display incorporating transparency as a metaphor for the exposed self.

Suzanne Anker's employment of MRI scans is less an exploration of identity than an occasion to provoke reflection on the processes of image production, their meaning and interpretation. In 'fMRI Butterfly' (2008; FIG. 2b), 15 seemingly unspecified and identical brain scans are arranged in a grid. At the centre of each frame is an image of a butterfly, on each of which Anker superimposes a different reproduction of a Rorschach-test-type inkblots. The overlays of the butterfly, MRI scans and inkblots yield nuanced variations in figure–ground relationships, creating in the viewer subtle optical illusions. In effect, although the butterflies are identical in each print, they seem different from one another. The complex system of the superimposed images evokes

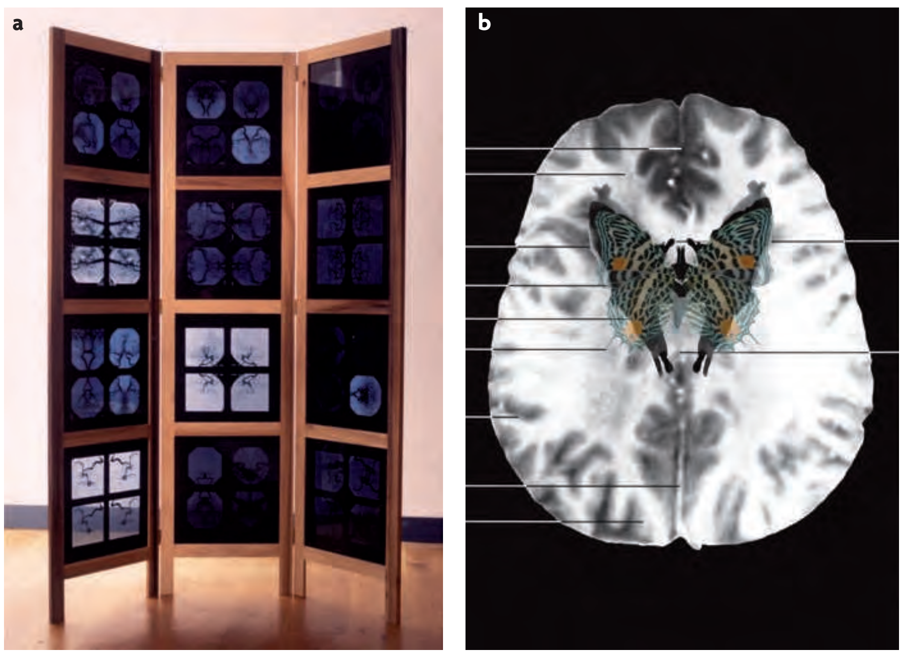

Figure 2 | **fMRI images in visual art. a** | Susan Aldworth (2001) Between a Thing and a Thought. **b** | Suzanne Anker (2008) fMRI Butterfly. Images are courtesy of the artists.

the underlying neurological processes at work in perception. This visual experience also underscores the non-univocal character of functional neuroimages and reminds us that these are end products of complex numerical data processing that involve intuition and interpretation on part of the scientist.

Confidence in the power of this technology has spurred a search for the underlying neural correlates of cooperation and competition, violence or religious experience, each of which carry ethical, legal, social and policy implications[31]. Commercial ventures, from neuromarketing to brain-based lie detection, are banking on the scientific aura of brain imaging to attract customers. Findings from neuroimaging studies have been illustrated and discussed in a myriad of cover stories in both scientific and popular magazines. The purpose of brain mapping by fMRI has been compared with the phrenological localisation of mental faculties[32]. Brain images referring to specific mental conditions address notions of normality and pathology.

Once disseminated through public media, these images have the power to alter conceptions of personality and identity. The high-tech approach of this technology grants this type of imaging scientific validity and objectivity among the general public[33,34]. However, it is noteworthy that fMRI data that reach the social setting have previously been interpreted by scientists and depend on the experimental setup and data analyses.

The 'neurochemical self'

The ascension to elevated mental states or techniques of self-intervention to modify behaviour or alter mental capacities and performance have been sought for a long time. We aim to achieve peace of mind through meditation, exercise or by listening to music, we skilfully aspire to improve our cognitive capacity by playing chess or memorising poems. Pursuits of this kind have become subject of neuroscientific examination seeking to understand how enriched settings can lead to changes in the brain.

Virtual reality. In the 1980s 'Star Trek' series, the starship 'holodeck' enabled its users to experience anything they wanted by recreating objects and people through a combination of matter replication, force fields, beams and holographic images. In Natalie Wood's feature film 'Brainstorm'[35], a 'hat' read sensations from a person's brain and wrote them on a tape that could be played back so that any subject could experience all the sensations of the original viewer.

Virtual reality is now far from fictitious, as virtual reality techniques have evolved and are widely applied in behavioural neuroscience to study brain–environment interactions and to modify behaviour or enhance cognition[36]. The creation of controlled, sophisticated, virtual settings allows to train individuals in the use of complex tools or respond to stimuli in simulated environments that would otherwise be too costly or hostile to actualise — as in the case of flight simulation or in the training of astronauts and firemen. Virtual reality is also extensively used in the context of neuroeducation or in cognitive therapy. One example is phobia desensitisation that lets patients overcome their fears by virtual exposure to the circumstances that trigger them[37,38]. Virtual reality instances are also commercially available as video game desktop interfaces. Similarly, neuroplasticity, that is, the brain's ability to change itself by remodelling nerve cell connections after experience, has become an emblem supporting video games, such as Nintendo's BrainAge*TM*, that aim to enhance mental fitness and prevent age-related memory decline. In both cases, fictional and utopian representations of mind-altering techniques have served as inspiration for the intensification of efforts in this field, confirming a dialogue between science and culture.

Chemical intervention. Deserving special attention is the achievement of mental states through chemical intervention, a salient feature in Western culture. In Damien Hirst's 'Lullaby Spring' (2002), a stainless steel cabinet holding 6,136 hand crafted and painted pills, evokes the widespread employment of pharmaceutical remedies for every aspect of health and malady. In this pharmaceutical cornucopia, pills are displayed as products of scientific craft and are presented as precious objects, like gems in a jeweller's display, or sweets on a tray. Similarly, 'Cradle to the Grave' (2006; FIG. 3), a large installation at the British Museum, explores the pharmaceutical approach to health. Based on composite patient records of eight individuals, the installation consists of a lifetime stock of prescribed drugs knitted into two 13-metre long fabrics. Each of them contains over 14,000 drugs (the estimated average prescribed to every person in Britain in their lifetime) and represents a sort of 'pill-diary' illustrating the medical and pharmaceutical histories of a man and a woman. Almost one thousand pills in the diary are antidepressants and anxiolytics.

Psychotropic medications have altered and eased patient experiences in a range of serious psychiatric disorders. Research efforts are currently being made towards the discovery and commercialization of novel, more effective classes of drugs[39]. Disseminated knowledge about the biological substrates of behaviour empowers individuals to manipulate their states of mind through the mere ingestion of such drugs as they understand their emotions and behavioural traits in chemical terms. Nikolas Rose asserts that we have become neurochemical selves, and are given the freedom (and

Figure 3 | **Pharmacopoeia.** Susie Freeman, Liz Lee and David Critchley (2006) Cradle to the Grave. Image is courtesy of the artists.

responsibility) to choose among an extensive selection of medications optimising our capabilities, performance and adaptations to the environment[40].

Artists have frequently experimented with mind-altering substances to determine whether they enhance or diminish creativity. Certain artists have produced work that either represents the artists' state of consciousness when creating the work of art, or evokes altered states of experience in the viewer. The drugs of choice have changed as culture has evolved[41]. In the 1950s, the eclectic artist Henri Michaux tested the effects of the psychedelic drug mescaline on his creativity, by drawing under its influence. Although recognizing its power, he condemned mescaline saying that it diminished the imagination and de-sensualised imagery[42].

Fearing the actualisation of Aldous Huxley's 'Brave New World', ethical concerns have been raised about whether psychotropic drugs should be used to treat legitimate disorders or as quick fixes to solve problems related to the exigencies of the life some individuals aspire to[43,44,45]. Moreover, a growing trend towards medication has increased the number of behaviours that are labelled as pathological and has influenced public health policies, thus reshaping boundaries between wellbeing and disease[46,47]. By the start of this century, the serotonin selective re-uptake inhibitor (SSRI) Prozac became a household word, an epitome of the modern pharmacological remedy, with millions of annual prescriptions, as well as numerous cult novels, films and memoirs based on it, such as Lauren Slater 's memoir 'Prozac Diary'[48] and the movie 'Prozac Nation'[49].

In works of art, especially through marketing campaigns, illustrations of psychotropic drugs evoke features that align with people's personalities and their lives' aspirations[50]. 'You must get out more, Mrs. Jones' (Phamacopoeia-Art Collection), is an extravagant, pink and red handbag with antidepressants and anxiolytics placed on its exterior insinuating that the owner requires these drugs to face people and the outside world.

In printed drug commercials and direct-to-consumer TV advertising (available in the USA and New Zealand), everyday individuals seem in need of the drugs sold to overcome worries arising from everyday hurdles in professional, social or interpersonal contexts. As in the case of prescriptive SSRIs such as Paxil, the range of depicted figures include the housewife who cannot cope with daily chores, the person who is afraid of others, the manager who is under pressure at work or young people waiting for a positive turn in their lives[51-53]. Besides the creative and interpretative depiction of medications in media advertising, the internet constitutes another powerful vehicle for drug promotion, as most available psychotropic medications have dedicated 'informative' websites. Hence, through images and narratives in the media (mainly advertisements and news) and the arts (film, literature, music and the visual arts) the general public is introduced to drugs that alter brain function, accentuating the notion of brainhood in everyday life.

Glossary

Brainhood
The condition of being rather than having a brain. Denoting a brain-based type of personhood regards the brain as the only organ in our body that we need in order to be ourselves (see also Supplementary information S1 (box) and Further information). It defines human beings as 'cerebral subjects'.

Cerebral subject
A term used to equate human beings with their brains.

Cultural imaginary
Term defined by the cultural historian Graham Dawson as a set of 'discursive themes, images, motifs and narrative forms that are publicly available within a given culture at any one time, and articulate its psychic and social dimensions'[5].

Neuroaesthetics
The study of art (in its conception, execution and appreciation) and aesthetic experience in neuroscientific terms[16].

Neurochemical self
Refers to how, in light of increasing biological knowledge of behaviour, we are recruited to a way of living in which our life is understood in chemical terms. Rather than implying essentialism or determinism, being a neurochemical self implies freedom and responsibility to alter our states of mind and choosing among a large selection of means to optimise our capacities and performance[36].

Neuroculture
Broadly refers to the incorporation of neuroscience knowledge into our life, culture and intellectual discourses. Several new terms with a 'neuro-' prefix have been used to designate the set of transformations taking place in society in light of advances in neuroscience (for example, neurosociety). In 2006, we used the term neuroculture to denote how neuroscience has specifically penetrated into popular culture and artistic expression[1].

Neuroeconomics
Combines the fields of neuroscience, psychology and economics for the study of how people evaluate gains, losses and rewards in economic decision-making. It adopts economic models and brain imaging techniques to identify the brain areas that become active when making a decision. It is to be distinguished from 'neuromarketing' that specifically adopts imaging tools to investigate customer choices for marketing purposes (for example, the study of brain responses to TV commercials).

Neuroeducation
Aims at developing novel teaching and learning methods combining pedagogy and findings in neurobiology and cognitive sciences. It involves the efforts of scientists and teachers and it stresses the importance of early-age brain modifications for the development of learning capacities and adult behaviour.

Neurotheology
Investigates neural phenomena underlying the subjective experience of spiritual phenomena and religious behaviour, such as prayer or ecstatic trance. It also uses brain-imaging tools and is based on the assumption of the universality and consistency of spiritual experiences across cultures and religions.

Personhood
Is the condition of being an individual person. It includes essential human properties such as consciousness, the ability to reason and self-awareness.

Rorschach test
Is a psychological test that examines personality characteristics and emotional states on the basis of the patients' perception of ambiguous images.

Conclusions

Discoveries in neuroscience are having a substantial effect on society and are pervading myriad aspects of our lives. Notions of the brain as a metonym for identity and self are becoming widespread. The significance of this knowledge-transfer from the laboratory to everyday living is exploited, represented and interpreted in our culture.

The collection of diverse neurocultural products (films, literature, the visual arts, as well as documentaries, news and advertisements) contribute to the construction and dissemination of brain-based narratives, thus shaping and reconfiguring concepts of human identity and parameters of social life, such as in healthcare and legal policies. The documentation of such products and of their public circulation highlight the dense mixture of social, political and personal changes that can arise from contemporary scientific progress. With our analysis we aim to raise general issues concerning the relationship between science and culture, specifically the arts, and its usefulness for exploring and facilitating public understanding of science (FIG. 4).

Neuroscience is a rich source of inspiration for the arts because of the universality of the questions it addresses. In particular, scientific images that render visible invisible phenomena, such as thought and consciousness, arouse artists' interest. Without offering explicit conclusions, art exposes

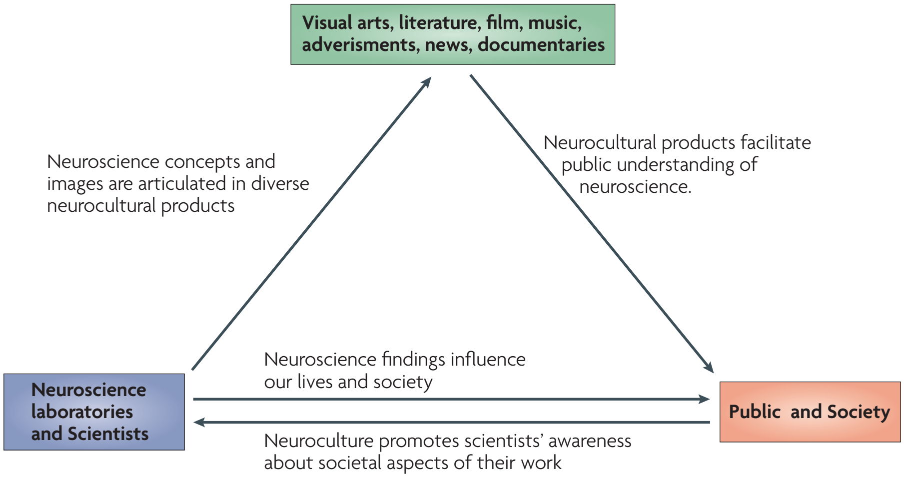

Figure 4 | **Representation of the triangular relationship between scientists, arts and the media, and the public.** This diagram shows how neuroscience concepts and images are articulated in diverse neurocultural products that facilitate the public understanding of neuroscience. However, the interaction is bidirectional, as not only do neuroscience findings influence our lives and society, neuroculture promotes scientists' awareness about societal aspects of their work and offers alternative viewpoints on questions shared among science, the arts and the humanities.

ambivalent possibilities and incites reflection and discussion about our individuality, at times with irony and ambiguity, which science can rarely afford. Artistic narratives offer alternative paradigms of human life based on a plurality of accounts and bring to light public concerns or hopes tied into scientific advances. Some of the original, at times whimsical, artistic representations of personhood, consciousness and behavioural manifestations remind us that these are all polymorphic phenomena shaped by biological substrata, culture, changing social norms and evolving practices.

Scientific knowledge grants a considered perception of the immediate benefits and dangers that can be drawn from its own investigation. However, the interaction of art and science is a means to explore, envision and critique possible futures and societal aspects of science's progression. Science inspires culture, but culture responds by highlighting the potential implications and consequences on the ongoing advances in a given field. Occasionally, science-inspired artistic creations are the starting point for the development of new tools, as in the case of the brain–environment interaction being explored in virtual reality.

We encourage scientists to actively participate in the dialogue between science and society by engaging in creative efforts that reflect on their work from different perspectives and to make their contributions to our scientific knowledge more palatable for the public.

Distinct initiatives involving neuroscientists, primarily in the form of art–science exhibitions[54], have served the purpose of highlighting the role of neuroscience research into the collective imaginary[55,56]. Last year in New York, a city-wide festival called 'Brainwave' dedicated to the neurosciences took place across a number of science, art and public venues. Through debates, lectures, seminars, exhibitions and performances various aspects of this branch of science were explored[2].

The Wellcome Trust in the UK and an increasing number of foundations (such as the Louise Blouin Foundation) promote and fund original collaborative partnerships across the arts and sciences specifically with the aim of reaching new audiences, which may not be traditionally exposed to science. An example of one such project is the online platform, www.neuroculture.org, which aspires to explore, document and share past and current manifestations of the neurocultural phenomenon, as well as promote the analysis and exchange of cultural projects intersecting neuroscience, the arts and the humanities.

The questions that neuroscience is attempting to answer have engaged artists and scholars since the time of ancient thought. While neuroscience continues to reveal the riddles of the brain and mind, the arts will continue to portray and interpret neuroscientific findings and engage the general public. Art leaves questions suspended, and provokes thoughts and imagination.

As writer Jonah Lehrer eloquently states, 'science needs art to frame the mystery, but art needs science so that not everything is a mystery'[57].

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FURTHER INFORMATION

Neuroculture website: http://www.neuroculture.org/
Brainhood project: http://www.brainhood.net/
European Neuroscience and Society Network: http://www.neurosocieties.eu/

SUPPLEMENTARY INFORMATION

See online article: S1 (box) | S2 (figure)

ALL LINKS ARE ACTIVE IN THE ONLINE PDF.

INNOVATION

The Allen Brain Atlas: 5 years and beyond

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Abstract | The Allen Brain Atlas, a Web-based, genome-wide atlas of gene expression in the adult mouse brain, was an experiment on a massive scale. The development of the atlas faced a combination of great technical challenges and a non-traditional open research model, and it encountered many hurdles on the path to completion and community adoption. Having overcome these challenges, it is now a fundamental tool for neuroscientists worldwide and has set the stage for the creation of other similar open resources. Nevertheless, there are many untapped opportunities for exploration.

The Allen Brain Atlas (ABA) is a Web-based, three-dimensional atlas of gene expression throughout the adult mouse brain, comprising a genome-wide image database of *in situ* hybridization (ISH) data, a high-resolution anatomical reference atlas and a suite of integrated search, navigation and visualization tools. From its inception, the ABA was intended to provide the scientific community with a powerful resource that would have a broad, positive impact on neuroscience research. At that time, the human and mouse genomes had been sequenced. With full inventories of available genes, the next challenge was to uncover their biological functions, and knowing where in the brain genes are expressed was expected to provide important clues to both gene and brain functions. In addition, technologies for high-throughput data production, management and informatics were maturing, making genome-wide studies and the integration of genomic and neuroanatomical data feasible.

This article looks back on the 5 years from the inception of the ABA to the present, highlighting some of the challenges that were faced in executing the project and the contributions that it has made to neuroscience. We discuss the advantages and caveats of using this unique resource, discuss how it is currently being used and point to untapped opportunities for further exploration. Finally, we describe the ever-expanding suite of related resources that have become available since the ABA was launched, and comment on those that will be coming in the next few years.

Development of the atlas

The ABA has its roots in a series of brainstorming sessions that began in 2001 and were led by James Watson, Steven Pinker and others. In these sessions, Paul Allen gathered together groups of scientists with interests ranging from molecular biology to human neuropsychology and asked "What can be done to help propel neuroscience research forward?" David Anderson of the California Institute of Technology put forward the concept of the ABA during these early discussions.

In January 2002, the US National Institutes of Health (NIH)held a meeting to chart the course of neuroscience research in the post-genomic era[1]. There, a host of scientists organized by Marc Tessier-Lavigne and Lubert Stryer concluded that "enormous benefit will derive from a systematic, large-scale, and organized effort to generate a molecular brain map for humans and the mouse"[1]. At that time, as part of the Gene Expression Nervous System Atlas (GENSAT) project[2–4], the National Institute of Neurological Disorders and Stroke (NINDS) was funding two complementary approaches to map gene expression in the mouse brain: one based on creating bacterial artificial chromosome (BAC)-transgenic mouse reporter lines for individual genes and one developed by Gregor Eichele and colleagues at the Max Planck Institute in Hannover, Germany, and implemented by Eichele and Christina Thaller at the Baylor College of Medicine, Texas, USA, using colorimetric ISH to map gene expression[5]. Soon thereafter, the NIH channelled its funding towards the transgenic mouse effort, which has subsequently generated over 800 transgenic reporter mouse lines, most of which have been deposited in the Mutant Mouse Regional Resource Centers (MMRRC)[6].