

Mental Versus Medical: How Deep Brain Stimulation Could Tip the Balance

A Research Paper

in STS 4600

Presented to

The Faculty of the

School of Engineering and Applied Science

University of Virginia

In Partial Fulfillment of the Requirements for the Degree

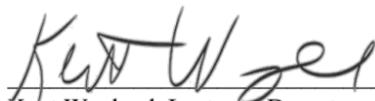
Bachelor of Science in Biomedical Engineering

By

Lydia Erbaugh

May 4, 2020

Approved:



Kent Wayland, Lecturer, Department of Engineering & Society

Date: May 4, 2020

Psychiatric disorders have become one of the leading causes of disability in the United States, with 20% of adults and 16.5% of adolescents afflicted by some form of mental illness (*Mental Health By the Numbers*, 2019). As the prevalence of these disorders has increased, the topic of mental health has become more widely discussed. Despite the open dialogue, long-held stereotypes surrounding psychiatric disorders remain in effect, such as the belief that psychiatric patients have the ability to control their abnormal behaviors. The biological model, which regards mental illness as biologically based in the brain, has been presented as a method to alleviate the stigma resulting from these stereotypes, but it has failed to be accepted. As a result, those struggling with psychiatric disorders continue to feel the burden of shame brought about by the stigma, which can exacerbate their illness. This shame can also prevent such people from seeking treatment for fear of the stigma they will face. However, as technology develops and clinical research progresses, more evidence is accumulating in support of the biological model. One such technology is deep brain stimulation (DBS), in which implanted electrodes electrically stimulate the brain. This therapy has proved to be effective in treating various psychiatric disorders, which strengthens the argument supporting the biological model by providing evidence that psychiatric disorders can be improved by treating the biology of the brain. The acceptance of this model in turn may have the capacity to revolutionize how these diseases are viewed by the public. The following analysis will explore the potential of DBS to diminish the stigma against psychiatric disorders by increasing acceptance of the biological model.

The Stigma of Psychiatric Disorders

The stigma surrounding psychiatric disorders dates back to the Middle Ages, when sufferers were believed to be possessed by evil spirits. While this particular belief has been

abandoned, the negative connotation of mental illness has been carried through the centuries, flagrantly reappearing as persecution of the mentally ill in multiple cultures such as Nazi Germany (Rössler, 2016). The resulting dangers posed by society toward the mentally ill caused psychiatric diseases to be considered a private matter within families (Borinstein, 1992). This custom facilitated the concept that these disorders were shameful, which made it even more imperative for those afflicted and their families to keep the illness concealed or locked away in a psychiatric institution. The resulting cycle of shame and secret continued until the policy of deinstitutionalization in the 1960's. Deinstitutionalization was a United States government program designed to improve psychiatric treatment by removing patients from insane asylums and providing them with a less restrictive environment (Flory & Friedrich, n.d.). However, with the reduced availability of long-term treatment, many patients ceased to receive any treatment, ending up homeless or in prison. As mental illness became associated with homelessness and poverty, the stigma grew based on misconceptions about the ability of patients to control their misfortunes. Because of their seemingly controllable behaviors, society began to view those with psychiatric disorders as less than hardworking and self-supportive, causing the blame to fall on the shoulders of the mentally ill.

Today, the weight of the stigma directed toward a person with mental illness largely depends upon how controllable the person's behaviors seem to be. People tend to differentiate between medical and mental illness by their assumptions of which can be controlled. Because the symptoms of medical diseases such as diabetes and cancer are obviously out of the patient's control, they are not held at fault for their condition. In contrast, psychiatric disorders manifest behaviorally and emotionally, which are functions that are thought to be under human control. It is difficult for those who are in control of their thoughts and actions to understand that people with

psychiatric disorders are not. This lack of understanding is made more severe by the complexity of psychiatric disorders (Bennett, 2015). While the underlying causes of many medical diseases are known, there is no extensive, comprehensive, or conclusive information available on how mental illness develops. Without a thorough understanding of the origin of these diseases, it is easier for society to put the blame on those who contract them. The stigma develops when they begin to believe that psychiatric patients allowed themselves to become sick through mere craziness, instability, or lack of intelligence. As opposed to medical illnesses, society views mental illnesses as more likely to alter what is considered the core “self” of a person, including their emotions, actions, thinking, perception, and consciousness. By making them seem less than human, this view generates fear and discrimination against those who are experiencing psychiatric illness. Society’s ingrained fear of people with psychiatric disorders is made worse by their portrayal in the media as violent, criminal, and disabled. Even though a very small fraction of mentally ill patients violently act out, these are the ones who are publicized. Cinematic portrayals of mental illness tend to be violent as well; therefore, most of society’s only impression of all psychiatric disorders is one of aggression.

Not only does the stigma against psychiatric disorders affect society’s attitude toward those with mental illness, but it also affects the patients’ attitude toward themselves. In fact, nine out of ten people with mental health issues claim that they have been negatively impacted by the stereotypes against their disease (*Stigma and discrimination*, 2015). Furthermore, the stereotypes experienced by a psychiatric patient are not always direct but can also be a self-perceived expectation of receiving discrimination since they know the stigma is present (Ahmedani, 2011). Sociologist Erving Goffman defines stigma as “an attribute that is deeply discrediting...[and] reduces someone from a whole person to a tainted, discounted one” (Goffman, 1963, cited in

Ahmedani, 2011, p. 3). As a result, this stigma forces an identity upon those with mental illnesses, specifically one that is corrupted. Society's belief that their core "self" has been altered by the disease and that they are at fault is often transferred to the patient themselves, bringing them feelings of guilt, shame, and inadequacy. By internalizing these beliefs that diminish their self-esteem and self-efficacy, their symptoms only deteriorate further. The stigma also negatively affects people with mental illness by making recovery more difficult (*Stigma and discrimination*, 2015). In an attempt to minimize the attention of others, they become less likely to seek or complete treatment, which leads to a cycle of worsening illness. The effects of these stereotypes against psychiatric disorders carry great ramifications for mental health patients, and a change in perspective in regards to these diseases is long overdue.

The Biological Model of Psychiatric Disorders

The biological model asserts that psychiatric disorders have a physical origin related to brain structure or function. This explanation views behavioral symptoms as an outward manifestation of abnormal activity or connectivity in the brain (McLeod, 2018). As Dr. Eric Kandel, a professor at Columbia University, describes it, "All mental processes are brain processes, and therefore all disorders of mental functioning are biological diseases" (Weir, 2012).

Within the scientific community, the biological perspective of psychiatric disease has been supported and developed by technology since its advent in the early 1900's. For example, electroconvulsive therapy provided early evidence for the theory as a treatment directly targeting the physical brain. The argument was advanced by the introduction of psychopharmaceuticals soon after. However, the underlying scientific principles of antipsychotics were not supported by credible research, and the biological mechanisms on which they were loosely based were later

disproved, limiting their impact on the biological model (McLeod, 2018). In contrast, recent progress in technologies such as genetic sequencing and medical imaging techniques have led to the discovery of more scientifically validated biological causes. For example, advanced imaging has enabled the observation of abnormal neural connectivity in schizophrenia (Rubinov & Bassett, 2011). Alterations in certain areas of the cerebral cortex have also been linked to severe depression through MRI imaging, and hypersensitive reward systems and bodily perception pathways have been related to eating disorders through similar methods (Weir, 2016; Alexander et al., 2019, p. 25). These findings have provided a preliminary foundation of support for the biological model.

Although recent advancements in the physiological origins of psychiatric diseases seem promising for the promotion of the biological model, the brain is still too complex for current technologies to discern. As a result, scientists have failed to identify convincing and comprehensive physical causes for psychiatric disorders, thus the biological model has not yet been widely accepted outside of the scientific community. Despite the mounting evidence, many remain skeptical of the model's simplistic explanation of mental illness due to the complexity of these diseases (Weir, 2012). It is difficult for non-experts to understand the premise of the biological model since the psychological manifestations of psychiatric disorders are seen but their underlying neurophysiological mechanisms are not. Without a thorough understanding of the physical basis, it is easier for society to accept psychological and environmental explanations of these diseases, which focus on the patient's cognition, behavior, and surroundings.

Another barrier to acceptance of the biological model is society's view of environmental factors as separate from biological causes. Because the connection between environment and biology is unrecognized, the latter is perceived as uninvolved in many cases even though it is usually an underlier. In fact, the intersection of psychological and environmental causes occurs

through biology since these factors are processed through neural connections in the brain. Kandel comments that “[Social and environmental factors] do not act in a vacuum, they act in the brain” (Weir, 2012). This idea can be demonstrated by comparison with diabetes, which is just one of many medical diseases resulting from the interaction of environmental and biological factors. Diabetes is primarily treated biologically, specifically through insulin injection, since the illness is characterized by how biology abnormally reacts to the environment. Although it is essential to treat the environmental aspects of the disease, such as diet and exercise, environmental treatment alone cannot fix the issue without a biological intervention. Likewise, psychiatric disorders result from a combination of biological and environmental interactions. For example, studies have found evidence that a person’s environment can alter their genetic code through what are called epigenetic tags, which can be inherited by their offspring (Malla et al., 2015). Not only does this phenomenon reveal how environmental causes become biological, but it can also account for the steady increase in psychiatric diseases as environmental defects are passed down through the generations. However, the relationship between biology and the psychological ramifications of an environment remains unaccepted due to widespread uncertainty about whether all aspects of cognition and behavior are the products of neuroanatomy, which has contributed to the lack of belief in the biological model.

Organizations such as the National Alliance on Mental Illness have attempted to improve public attitudes toward psychiatric disease by facilitating widespread acceptance of the biological model with the catchphrase, “Mental illness is just like any other medical illness” (Malla et al., 2015). These campaigns have been somewhat successful in convincing people of this biological perspective, which has impacted the stigma surrounding mental illness in both positive and negative ways. Since their symptoms could now be perceived as outside of their control, the

biological model has mitigated some stereotypes by absolving patients of responsibility for their disorder (Haslam & Kvaale, 2015). However, the biological model has failed to eliminate the stigma toward mental illness by creating new stereotypes. Although their perceived lack of control removes the blame from those with psychiatric disorders, it also implies that they are more unpredictable and dangerous precisely because they cannot control their own actions. As a result, the biological model has increased society's fear of those with mental illness while decreasing confidence in their ability to recover since it is now understood that it is not a choice the patients can simply make. These misunderstandings have caused the biological model to fail in changing public attitudes thus far despite changing their beliefs. However, technological advancements such as deep brain stimulation may have the potential to fill in these gaps in understanding.

Deep Brain Stimulation for Psychiatric Disorders

Deep brain stimulation (DBS) is a procedure in which surgically implanted electrodes emit electrical impulses to surrounding areas of the brain. The device is controlled by a pacemaker that is simultaneously implanted in the chest (Provenza et al., 2019). By targeting disorder-specific areas of the brain, DBS has become a viable treatment option for the biological aspect of psychiatric disorders. The stimulation administered by this therapy affects mental functions such as emotion and behavior, and its effects act in an immediate switch-like manner, making it faster than most other treatments (Kopell et al., 2004). Because of the therapy's invasiveness, DBS is typically used as a last resort for those who are not responding to medication or other customary psychotherapies, but the procedure is powerfully effective. The therapy's rousing success gives DBS the potential to alleviate the pessimism surrounding the ability of psychiatric patients to recover from their biological afflictions, which was one of the concerns brought about by the

promotion of the biological model. Because this misgiving tends to heighten the stigma against psychiatric patients, DBS may be able to relieve this and other misguided notions from the biological model that maintain the stigma.

To explore the ability of DBS to modify cultural perceptions of psychiatric disorders, both scientific and non-scientific literature was examined, including psychology articles, blog posts, and neuroscientific discoveries. Social psychology articles concerning the public understanding of science were used to discover how technologies are integrated into a cultural belief system, specifically within the field of neuroscience. Videos and news articles were viewed to explore media portrayals of DBS, which heavily impact how the technology is viewed by the general public. In particular, these sources provided evidence that specified why the biological model has not yet provided a solution to psychiatric stigma. To follow up on these findings, more scientific literature was reviewed to determine how DBS could work around the issues previously encountered in the biological model. To provide an unbiased perspective, research was also performed on how DBS may not support the biological model by failing to fill in the gaps left by previous technologies. The findings were synthesized into a process that DBS must follow to change societal belief systems as well as the therapy's likelihood of doing so.

Changing Perspectives of Psychiatric Disorders

For DBS to change societal perceptions of psychiatric disorders, multiple steps must be taken towards the integration of the biological model into cultural belief systems. First, DBS must become a common neuroscientific technique, which requires it to be widely regarded as a trustworthy therapy by clinicians and patients alike. Only then can the biological model gain support from the technology. The process of accepting the model begins with the appearance of

supporting evidence in the media, including the use of DBS. The concepts introduced through this method must then be transferred into society's common vocabulary, from which they can be subconsciously integrated into each person's beliefs. While the process is clear, the ability of DBS to follow this framework is not.

In order for DBS to fully support the biological model, it must first be accepted as a reliable therapy. Although electrode implantation is minimally invasive and relatively safe for a neurosurgery, the concept of tampering with the brain both during and after surgery is intimidating and difficult for people to accept as common practice. As a result, the current level of trust in the technology is limited by its unlikely but serious negative side effects. In fact, the current state of the media and scientific literature concerning DBS is distinctly divided into praises for its miraculous potency and critical reviews of its hazards, which include the typical risks of neurosurgery such as internal bleeding, stroke, and seizures (Schlaepfer et al., 2013). Furthermore, a large portion of this literature specifically focuses on the controversy surrounding the perceived ability of DBS to alter the patient's personality through its effects on mood, behavior, and emotional processing. The resulting behavioral changes include impulsivity, aggression, and hypersexuality (Levine, 2018). This process can be construed as dehumanizing since the technology makes the patient's autonomy subject to control by a computer. However, the same attitudes were held toward psychopharmaceuticals in their early stages. Just as psychiatric drugs are now widely accepted as routine therapy despite their personality altering effects, DBS may eventually become a normalized treatment as well. However, it is still unknown whether the technology will be able to change societal perceptions of psychiatric disorders via the biological model when it does become widely accepted as a therapy.

The next step in the process of changing attitudes toward psychiatric disorders is the integration of the biological model into cultural belief systems. The mere existence of DBS and its wide body of literature indicates at least a rudimentary acceptance of the biological model in the scientific community. In order for scientists to begin applying DBS to psychiatric disorders, they must have believed that these illnesses were biologically based in the brain as did the first patients to undergo the surgery. As the procedure begins to yield more success stories and gain recognition in both science and mainstream media, it may in turn be able to contribute to more widespread acceptance of the biological model. However, using technology to change the entire cultural belief surrounding mental illness is difficult because an individual's previous experience with science determines their willingness to accept new scientific information (Wynne, 1992). According to social representation theory, people selectively interpret scientific information to comfortably integrate it into their belief systems, which often leaves their beliefs nearly unchanged and prevents revolutionary changes in thinking. In fact, studies have observed active resistance to neuroscientific concepts that threaten an individual's established preconceptions (O'Connor & Joffe, 2013). Therefore, even if DBS is accepted as a successful therapy for pathophysiological states of the brain, it may not be able to nullify other, more long-held explanations of psychiatric disorders.

For a belief to become truly integrated into society and take precedence over previously held beliefs, its supporting information must be relevant, appearing through various interpretations in the media where it will be seen and understood. From both its presentation in the media and the ensuing public discourse, the concept converges on specific interpretations that have the ability to fundamentally change societal ideologies (Wagner, 2007). In this way, public understanding tends to be rooted in the media, which gives DBS an advantage in deeply affecting cultural belief

systems. Because the news tends to focus on miraculous recovery stories, DBS can seem almost magical to the non-expert. Popular documentary shows such as 60 minutes on CBS render DBS as “life-giving” and “breath-taking” (Colihan, 2008; Garcia, 2017). These compelling descriptions of a biological treatment contribute to fundamental shifts in opinion concerning the source of mental illness. However, DBS is not a miracle cure for psychiatric disease, so whether its evidential strength beyond its portrayal in the media is enough to change public opinion remains in question.

For integration into cultural belief systems, concepts must shift from the media into society’s everyday vernacular. This stipulation is a positive sign for the acceptance of the biological model via DBS since people tend to draw new conversational phrases from media portrayals of neuroscience. Everyday vocabulary is often subconsciously derived from current neuroscientific fact to give the brain a causal role in behavior and reduce mental phenomena to simple brain processes for a more common sense understanding. For example, someone who has read a scientific article about how the brain’s reward systems participate in the development of cravings might comment that their “brain wants chocolate”. Part of the reason neuroscientific jargon is readily substituted for behavioral phenomena in this way is because people prefer the physical conception of abstract ideas (Rodriguez, 2006). Given its support of a physical explanation for psychiatric disorders, DBS is in a good position to provide the scientific information necessary to move the biological model into our common vocabulary. This adoption of neuroscientific jargon is likely to be followed by true belief in the concept, thus reducing psychiatric behavior to biological processes.

Despite the promising role of DBS in cultivating belief in the biological model, previous technologies for psychiatric treatment have failed to effectively move the biological model through the process of integration into cultural belief systems. Psychopharmaceuticals, genetic sequencing,

and neuroimaging all had the potential to revolutionize cultural perceptions of psychiatric disorders via the biological model, but none have succeeded thus far. DBS has some unique aspects that may enable it to be more successful in this area such as a direct connection to the brain and compellingly strong therapeutic outcomes. For example, DBS treats the underlying cause of psychiatric disorders unlike antipsychotic drugs, which merely treat the symptoms of the disease (McLeod, 2018). However, DBS itself does not elucidate the specific biological basis of certain psychiatric disorders. At this point in time, the technology only makes it clear that these mechanisms exist, which may not be convincing enough to move the biological model into the public eye. Furthermore, it is not yet completely understood how DBS functions to treat psychiatric disorders. Current research continues to investigate the underlying pathophysiological neuroanatomy of psychiatric disorders in order to correctly place the implanted electrodes, which creates uncertainty in the legitimacy of the technology and thus the biological model (Levine, 2018). Just as antipsychotic drugs failed to support the biological model because they were not supported by sound scientific evidence, DBS currently does not have the scientific foundation to facilitate belief in the biological model. While the technology has the potential to gain the necessary evidentiary support, this dilemma implies that there is an unmet requirement for DBS to achieve before it can gain the potential to change societal belief systems. In order for DBS to effectively support the biological model, it may require identification of a specific physiological mechanism for psychiatric disorders. While this goal has not yet been achieved, DBS itself facilitates this research both in attempts to improve the technology and by observing the results of targeted stimulation to specific areas of the brain. As this research continues, it paves the way for more scientific discoveries that build up firm support for the biological model.

Conclusion

DBS technology is not currently poised to change societal perceptions of psychiatric disorders, but it could achieve this state in the near future. To do so, the procedure must be culturally accepted as a trusted therapy followed by integration into everyday vernacular and established belief systems, but the technology first requires stronger links to the underlying neurobiology. DBS is already more directly related to biological pathophysiology than previous psychiatric treatments, but it is still not understood enough for non-experts to grasp. Since the specific scientific basis is not yet understood, DBS has encountered barriers in acceptance as a treatment and as support for the biological model. However, as neural discoveries are developed through DBS and confidence in the therapy grows, it is likely that the underlying neuroscience will facilitate widespread belief in the biological model, especially due to the positive media portrayal of DBS. The direct connection between this treatment and neurobiology has the potential to fill the gaps in biological understanding left by previous psychiatric technologies, which could eventually lead to a better cultural understanding of psychiatric disorders.

In a cyclic manner, cultural acceptance of the biological model would lead to improvements in DBS technology and other psychiatric treatments due to the shift in perspective regarding mental illness. The prospect of improved treatment through acceptance of the biological model provides hope for patients since the possibility of more biologically based treatments could alleviate the difficulty experienced in current treatment and recovery processes. Most importantly, the biological model has the potential to diminish the shame experienced by these patients, for it emphasizes that there is not something inherently wrong with their personality. By framing their disorder as a mere medical disease, it changes their perspective of the disorder from encompassing who they are to just a person with an illness. On a larger scale, belief in the biological model would

contribute to the long-held philosophical debate surrounding whether personalities are biologically based. It is currently unknown how our characters manifest and where they originate, but the biological model emphasizes the role of physiology in these constructs. Therefore, through its support of the biological model, DBS has the ability to change society's view of identity and thus its perceptions of psychiatric disorders.

Citations

- Ahmedani, B. K. (2011). Mental Health Stigma: Society, Individuals, and the Profession. *Journal of Social Work Values and Ethics*, 8(2), 4-1-4–16.
- Bennett, T. (2015, April 16). *Changing The Way Society Understands Mental Health*. National Alliance on Mental Illness. <https://www.nami.org/blogs/nami-blog/april-2015/changing-the-way-society-understands-mental-health>
- Borinstein, A. B. (1992). Public Attitudes Toward Persons With Mental Illness. *Health Affairs*, 11(3), 186–196. <https://doi.org/10.1377/hlthaff.11.3.186>
- Colihan, K. (2008, July 24). *Deep Brain Stimulation for Depression*. <https://www.cbsnews.com/news/deep-brain-stimulation-for-depression/>
- Flory, C., & Friedrich, R. (n.d.). Half a Million Mental Patients Liberated from Institutions to Community Settings Without Provision for Long-Term Care. *Mental Illness Policy Org*. Retrieved February 1, 2020, from <https://mentallillnesspolicy.org/imd/deinstitutionalization-flory.html>
- Garcia, L. (2017, May 31). *State of Mind Episode 5: Out of the depths*. <https://www.cbsnews.com/news/depression-neurosurgery-dbs-mental-health-uncharted-state-of-mind-episode-5/>
- Haslam, N., & Kvaale, E. P. (2015). Biogenetic Explanations of Mental Disorder: The Mixed-Blessings Model. *Current Directions in Psychological Science*, 24(5), 399–404. <https://doi.org/10.1177/0963721415588082>
- Kopell, B. H., Greenberg, B., & Rezai, A. R. (2004). Deep Brain Stimulation for Psychiatric Disorders. *Journal of Clinical Neurophysiology*, 21(1), 51–67.
- Levine, D. (2018, January 9). Deep Brain Stimulation for Mental Illnesses Raises Ethical Concerns. *Leapsmag*. <https://leapsmag.com/deep-brain-stimulation-mental-illnesses-raises-ethical-concerns/>
- Malla, A., Joobar, R., & Garcia, A. (2015). “Mental illness is like any other medical illness”: A critical examination of the statement and its impact on patient care and society. *Journal of Psychiatry & Neuroscience : JPN*, 40(3), 147–150. <https://doi.org/10.1503/jpn.150099>
- McLeod, S. (2018). *The Medical Model*. Simply Psychology. <https://www.simplypsychology.org/medical-model.html>
- Mental Health By the Numbers*. (2019, September 1). National Alliance on Mental Illness. <https://www.nami.org/learn-more/mental-health-by-the-numbers>

- O'Connor, C., & Joffe, H. (2013). How has neuroscience affected lay understandings of personhood? A review of the evidence. *Public Understanding of Science*, 22(3), 254–268. <https://doi.org/10.1177/0963662513476812>
- Provenza, N. R., Matteson, E. R., Allawala, A. B., Barrios-Anderson, A., Sheth, S. A., Viswanathan, A., McIngvale, E., Storch, E. A., Frank, M. J., McLaughlin, N. C. R., Cohn, J. F., Goodman, W. K., & Borton, D. A. (2019). The Case for Adaptive Neuromodulation to Treat Severe Intractable Mental Disorders. *Frontiers in Neuroscience*, 13. <https://doi.org/10.3389/fnins.2019.00152>
- Rodriguez, P. (2006). Talking brains: A cognitive semantic analysis of an emerging folk neuropsychology. *Public Understanding of Science*, 15(3), 301–330. <https://doi.org/10.1177/0963662506063923>
- Rössler, W. (2016). The Stigma of Mental Disorders. *EMBO Reports*, 17(9), 1250–1253. <https://doi.org/10.15252/embr.201643041>
- Schlaepfer, T. E., Bewernick, B. H., Kayser, S., Mädler, B., & Coenen, V. A. (2013). Rapid Effects of Deep Brain Stimulation for Treatment-Resistant Major Depression. *Biological Psychiatry*, 73(12), 1204–1212. <https://doi.org/10.1016/j.biopsych.2013.01.034>
- Stigma and discrimination*. (2015, August 7). Mental Health Foundation. <https://www.mentalhealth.org.uk/a-to-z/s/stigma-and-discrimination>
- Wagner, W. (2007). Vernacular science knowledge: Its role in everyday life communication. *Public Understanding of Science*, 16(1), 7–22. <https://doi.org/10.1177/0963662506071785>
- Weir, K. (2012, June). *The roots of mental illness*. American Psychological Association. <https://www.apa.org/monitor/2012/06/roots>
- Wynne, B. (1992). Misunderstood misunderstanding: Social identities and public uptake of science. *Public Understanding of Science*, 1(3), 281–304. <https://doi.org/10.1088/0963-6625/1/3/004>