

Science AMA Series: I’m James Owen Weatherall, physicist and philosopher at the University of California, Irvine. I wrote a book about how the concept of nothingness—the absence of stuff—has been central to centuries of physics theories. AMA!

PhysicsToday ¹ and r/Science AMAs¹

¹Affiliation not available

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Abstract

I’m James Owen Weatherall, a professor of Logic and Philosophy of Science at the University of California, Irvine, where I’m also a member of the Institute for Mathematical Behavioral Science. I’m interested in the mathematical and conceptual foundations of physics, model-building in finance, and epistemology more broadly. In my new book *Void: The Strange Physics of Nothing*, I talk about the historical and conceptual issues related to the physics of “nothing,” from controversies about empty space in the 17th century to the strange features of the vacuum state in quantum field theory today. You can read more about it in this interview with *Physics Today*. I’m also the author of *The Physics of Wall Street*, which looked at how modeling ideas moved from physics into finance during the 20th century. And right now I’m writing a book on why false beliefs persist and spread, even when everyone cares about believing true things about the world. I’m looking forward to talking about the philosophy of physics, finance and mathematics, and of course, nothing. I’ll be back at 4pm EDT to answer your questions! EDIT: That’s a wrap. Thanks for the great questions!

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Hello James! Thank you for taking the time to answer questions.

I'm interested in the general consequences of Quantum Physics to our understanding of reality. What's your take on local realism, or what in other words can be described as "every event has a cause at *one* place and *one* time"?

On another tack, in your studies on 17th discussions on vacuum, is it possible to detect a shift from fantasies presented with certainty to admission of ignorance and questions that could possibly find an answer in the future? My reading of "Sapiens" and other work on Medieval thought suggests that before the 15th century, people were poor at admitting ignorance and systematically exploring difficult concepts, as well as imagining a future with people with better insight than their own.

[helm](#)

Thanks for these questions! I am going to answer the second one first, then come back to the first one.

I think you are getting at a very interesting development that occurred during the 17th century. (I don't want to claim that no one was good at understanding uncertainty before the 17th century -- there were some very good Hellenic scientists for instance. But I do not know enough to weigh in on this in detail.) There is a huge difference between the way that Rene Descartes, who tried to develop a systematic

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theory of physics (and everything else) a few decades before Newton, thought about how confident he could be in his theories, and how Newton approached the same question. Descartes believed that he had developed a way of learning about the world that could lead to absolute certainty. Basically, he thought that by reasoning from some basic principles that he believed to be irrefutable, he could derive what the laws of physics must be. What he came up with is remarkable because of the intricacy of the arguments -- but also because of the complete and total failure to accord with even the most basic experiments. But he never revised these laws, because he didn't think it was possible for him to be wrong. Instead, he tried to come up with ever more elaborate explanations for why they didn't work.

Newton turned this one its head, and reasoned much more directly from experimental and observational phenomena. And while he seemed to take some things to have been established definitively, on many points he explicitly argued that what he was offering was merely "very probable" rather than certainly or necessarily true, and he seemed to think that some future theory could well replace his.

Even so, a modern understanding of issues like error and uncertainty wouldn't come until much later -- for instance, in the work of Laplace in the late 18th and early 19th century.

Hi James, thanks for doing this! I'm studying physics, and I've recently been getting quite interested in areas such as industrial ecology and complex systems, using modelling tools such as systems dynamics (SD) and nonlinear DEs.

What I find particularly fascinating in the field of complex systems is how diversely applicable some particular equations are. For example, the logistic function is used in ecology, neural networks, chemistry, and even in linguistics and economics. Even in more simple nonlinear systems like harmonic oscillators we see [equivalent systems](#).

We're also beginning to see transdisciplinary approaches to researching complex systems, such as in sustainability institutes and design firms, which typically blend quantitative and qualitative methodologies. I just think that's interesting!

Here's my question:

What do you think about the role of analogy in solving problems from seemingly unrelated systems? Say you have two (complex) systems, A and B. A is testable (such as an ant colony), but B is not (some economic phenomenon):

- When can you say that A and B are equivalent?
- Say you run some experiments on A and find some results - can we ever make epistemological claims about B without being able to run experiments on it?

[LithiumEnergy](#)

This is a really great question. I think we use analogical reasoning in science all the time -- and there is some sense in which all applied mathematics is based on analogical reasoning, insofar as you are studying the properties of mathematical structures that you think are suitably related to (similar to? analogous to?) physical, or economic, or biological systems.

I would say that there certainly are cases where analogical reasoning allows you to solve problems in one area of science by reasoning about a system in other areas. Maybe the most striking example of this from recent history in physics concerns Hawking radiation. Hawking radiation was predicted by Stephen Hawking in 1974, using a combination of methods from general relativity and from quantum field theory. The calculations seemed to predict that black holes actually radiate particles (so they aren't perfectly black!) and that with enough time, they will actually evaporate.

But is this true? Well, the radiation would be very weak, and so it is basically impossible to test

Hawking's theory. And it turns out that some of the arguments Hawking used to make the prediction are difficult to make perfectly precise and satisfying. But it turns out that there are some other systems, for instance using ultracold atoms in a special state known as a Bose Einstein condensate, that should also exhibit Hawking radiation. And in a really remarkable experiment a few years ago, Jeff Steinhauer, a physicist at Technion University in Israel, managed to observe Hawking radiation in a laboratory system.

This is an amazing experiment, but what does it actually teach us? Well, one thing it does not show is that there exist any black holes in the universe. (We have very good reason to think there are black holes, but those reasons have nothing to do with Steinhauer's experiment.) It also doesn't definitively show that actual black holes do emit Hawking radiation. (Presumably we would need to see a black hole radiating to do that.) What I think Steinhauer's experiment shows is that the sorts of arguments Hawking used to derive black hole radiation in the first place are reliable and sound (because it is very similar reasoning that leads to the prediction of radiation in Steinhauer's analogue experiment). So if you already think black holes exist, and you also think that Hawking's arguments, if valid, would apply to black holes, then I think Steinhauer's experiment should make you more confident that black holes actually do radiate.

What's interesting about this example, I think, is that it shows how powerful analogies can be in scientific reasoning, but it also shows how careful you need to be when you try to draw inferences based on analogies. Some things do follow, but a lot doesn't.

Do you explore the Philosophical angle of Nothingness in your book?

[aditseth03](#)

You bet! Though there are a lot of philosophical angles to consider, and I don't discuss all of them. For instance, I do not discuss religious or theological issues that could arise, and I do not talk about "Nothingness" in, say, the sense that Sartre seems to have in mind in *Being and Nothingness*. Really, it's a book about empty space and the absence of matter.

But I think that's still plenty philosophical. One of the main things I argue for in the book is that what we mean by "nothing" in physics has changed pretty dramatically since the 17th century (and it changed in the 17th century from what came before). I think that we need to think about the philosophical questions you might ask about "nothing" from the perspective of these changes in physics. After all, when we have informal conversations about "nothing", not in the context of physics, we are still considering some way that we imagine the world could have been, i.e., some physical (or maybe metaphysical) possibility in which there isn't anything. And I think physics is a much better guide to what those possibilities are than our pre-theoretic intuitions.

Dr. Weatherall! I took your CHP course on the nature of time about a year ago and had a ton of fun. Thanks again.

My question: In your interview, you talk about how Einstein's equations have vacuum solutions, but obviously, we live in a universe where matter exists. Why might a universe with matter be favored (if that's the right word) over a vacuum universe, if they're both valid solutions?

[TopsyTurnip](#)

I'm glad to hear you liked the course! I am looking forward to teaching it again this Winter.

I am not sure that a satisfying answer to this question is possible. You might first ask: when would a universe with the particular matter we see be favored over one with a little mess matter, or one with a

little more? For instance, is the universe that contains Pluto favored over one that doesn't---or one that has another, larger planet outside of Neptune's orbit? There's a way of thinking about this sort of question that focuses on how Pluto came to be where it is, beginning, say, with the distribution of gas and dust swirling around the sun early in the history of the solar system. But if you really mean "why does that chunk of matter exist at all", I'm not sure anything can be said.

The question about vacuum solutions, I think, is just the same sort of thing in an extreme form. Could there have been much less stuff in the universe? Yes. Could there have been no matter at all? Again, according to general relativity anyway, yes. Is there some reason why the world must be the way it is? Probably not. (Although, of course, there are selection effects: if the universe had no matter, we wouldn't be here to write about it. So there's a strong reason to think that universes in which there are people are universes that have a certain minimal amount of matter -- but not too much matter.)

On the other hand, there are theories out there that go beyond general relativity to try to explain why there must be matter in the universe. For instance, some people (most famously Lawrence Krauss) have argued that the vacuum state in quantum field theory is unstable, and so if the universe were in a state of "nothing" it would generically evolve into a state with "something". So you might think this is a reason why universes with matter are favored. I think you could argue that some other cosmological theories, such as Roger Penrose's Conformal Cyclic Cosmology, attempt to do something similar, by arguing that the universe goes through cycles, and that properties of past universes show up in subsequent ones in a different form. For instance, he thinks dark matter may be a signal from past cycles of the universe. Perhaps you could develop a theory in which ordinary matter, too, is left over from some other sort of thing in a past universe, so that if you took any universe and just let it evolve for long enough, eventually there would be some matter.

Seems like your next book has piqued my interest. There's so many variables to consider. It's also ironic to bring up that topic in the Mecca of that phenomenon.

It's also difficult for me to grasp what angle you're going to be discussing it from since it overlaps through psychology, social tendencies and then the physics/philosophical side.

Touching on that last point, isn't it difficult to even say definitively that were accepting an incorrect perspective? Since almost all understanding through science is only relative to the knowledge we've accumulated up to this point (and everything is really based on probability), does it even make sense when dealing with topics that are heavily shrouded in non-definitive and pseudoscience to definitively know that were actually correct (inaccurate measurement techniques, erroneous assumptions that fit theories to observations, instead of creating theories based on observations)?

A basic example is how Newtonian physics can properly model the majority of the motion of the planets. But it cannot be used to accurately predict mercury's orbit. Relativity can predict it.

But consider here, that even pre-Einstein it was human nature to try and come up with reasons as to why mercury's orbit still fit in the Newtonian model (they'd say there was another mass acting on it that we can't see, or because there was a force interacting with it in the ether). That was deemed as the "correct interpretation". The issue with this logic that is so inherent in humanity, is that we are more likely to accept error if the majority of our observations meet our theories when the observations could actually be pointing at a different reasoning altogether.

Here's a few examples: Parents believe vaccines cause autism. Renewable power is better for the environment than nuclear (or is the solution to our energy needs). Global warming is the cause of numerous natural disasters, and that our actions will place us in unprecedented peril.

Even though modern science may have progressed since Newtonian times, are we not still adhering to the belief that our science is infallible, and the mathematical probability shouldn't be disputed?

I mean what if vaccines don't cause autism, but maybe the collective conscious belief that it does is actually the true source for the increased rate of diagnosis? Yes, I'm implying that human thought is influencing our reality. Who's to say it isn't? Human consciousness isn't understood, but how we interact at a quantum mechanical level implies there's more to it.

Or for renewables, it's just an omission of variables that people are neglecting when they adhere to the popular belief. They don't consider the rare earths involved in battery manufacturing, the increased waste from the batteries themselves, transport and transmission of power, the infrastructure that needs to be built and maintained in order to remain operational...when nuclear could do all that at a fraction of the impact.

Global warming is the one that intrigues me the most. I think it's like a chemistry experiment trying to predict the temperature of water after leaving it in a room for a specified period of time. Sure, the math might bring you close to your predicted time to reach a certain temperature..but it rarely works. Why? Because air convection currents aren't properly accounted for, or the material the water was in wasn't consistent, maybe the device for recording temperature or pressure wasn't accurate. Sure, the more you isolate those components and conduct the experiment in a vacuum, the more likely you'll see your observations fit closer to expected values.

But that's just it right? We're talking about something planet sized here where we're piecing together data from a large multitude of sources that are subjected to not only imprecise measurements, but also conducting the evaluations in a vacuum. It's not accounting for all the variables since it's not only difficult to be quantifiable at that scale, but there are most likely contributing factors that have a probable impact; they're just not identified yet. Time also isn't properly accounted for. You can simulate and model all you like, but what happens to those models if Yellowstone blows? Or a disease strikes (from all those anti-vaccers) that cuts population and consumption from those models. What if a new GMO comes along that is extra proficient at carbon capture? Or if we stumble upon reliable functioning nuclear fusion.

All these things don't even really touch (directly) on the psychological side. But even if we do align with impractical logic, isn't it better to have that opposition? I mean, if there wasn't doubt, science would never have to progress.

Sorry, I guess I wrote a book. If you read all of that, you can probably notice I err on the side of skepticism. I also lack the mathematical background to fully see things through a more definitive perspective. Will this new book address the things I mentioned here?

Cheers!

[toughonstains632](#)

Wow! There's a lot here. I say a bit below in an answer to a different question about what Cailin O'Connor (my co-author) and I are trying to do in the book. But actually, one of the big themes of the book is how to think about the sorts of skeptical concerns you raise here. Science has very often turned out to be wrong in the past. Scientists are people, and people are fallible, biased, and corruptible. We can never be perfectly certain about anything -- after all, some assumption we've been making could turn out to be false, or things could change in ways we don't anticipate, or we could have just made a mistake.

The way Cailin and I think about these issues is that we (i.e., each of us individually, but also the collective "we") need to make decisions and take actions in the world. We choose how to do so on the basis of what we expect the consequence of those actions to be: will we hurt ourselves, hurt other people, get what we want, etc.? And we'd like our predictions about the consequences of our actions to be as reliable as they can be. How are we going to do that? I do not see any better way than to gather as much evidence and understanding as we can of how the world works, and how our actions will affect it. We'll never be certain, and we can always be wrong. But when it comes time to actually do

something, we need to make use of the best understanding we have.

With global warming -- which I'll focus on because it's what you say you're most intrigued by -- there are some basic things that I think we completely understand. One is that some gases are transparent to visual light, but opaque to infrared radiation (heat). These tend to let light from the sun in, but then trap the heat produced when that light interacts with the surface of the earth. These include water vapor, methane, and carbon dioxide, among other gases. We know that the concentrations of these gases affect the surface temperature of planets: for instance, Venus has an atmosphere of almost entirely carbon dioxide, and has a very high surface temperature compared with Mercury, even though Mercury is closer to the sun; the moon has no atmosphere, and its surface temperature swings wildly as a result, but on average it's much colder than the Earth even though it's at the same average distance from the sun. We also know that we have released enormous amounts of carbon dioxide into the atmosphere, that the levels of carbon dioxide persisting in the atmosphere have steadily risen over the last 60+ years, that average global temperatures have risen consistently over the last 20 years, and that our best measurements of carbon dioxide levels and temperature seem to track one another very well. Finally, we have geological evidence that the climate was very different in past periods when both carbon dioxide levels and temperatures were higher. Of course, there's other stuff, too.

This basic understanding of what's going on doesn't mean that we have perfect control over how weather patterns will change, or whether there are possibly feedback loops the we do not know about that could moderate (or accelerate) climate change in the future, or even if climate change is necessarily bad. But a lot of people have tried very hard to identify such processes, to test whether they really occur and measure their effects, and to update our expectation in light of them. And when we take it all together and we try to predict what will happen, using the best understanding we've got, things don't look good. It seems to me that that is sufficient basis to try to change out practices -- not because we are certain about the future, or that science is infallible, but rather because on the whole there's a lot more reason than not to think that continuing on our current path is going to create problems we won't be able to solve and that will lead to a lot of suffering.

- 1) How do we know that nothingness is true nothingness? The absence of some quantity might imply the presence of another at a given point.
- 2) What do you have to say about the absence of information?
- 3) Can nothingness truly have no speed limit?

[MasterAgent47](#)

(1) I think there are two separate questions to consider. One is: what is "true nothingness" (or at least, what's closest to "nothingness") according to a given physical theory; and the other is: is that physical theory true? Whether or not the presence or absence of one quantity implies anything about the presence or absence of another quantity is the sort of thing that a given physical theory will generally bear on. So in general relativity, just to take an example, the absence of matter does not generally imply the presence of any other quantity (though there is always geometry at any point). But it may be that there's some alternative theory that does imply the existence of some other quantity that we do not know about. (2) I do not think of information as an entity. Rather, I understand it as a way of describing statistical relationships between different systems. Absence of information, then, is just a lack of a certain kind of correlation... (3) Well, if matter has a speed limit (which it apparently does), then surely nothing must, too, since an isolated region in which there is no matter can move only as fast as the matter in the region it is moving towards can get out of the way!

Hi james... I do try to understand why false rumors and news are widely accepted as fact by asking

questions to the common people including on Reddit sometimes... I have pulled this out of your interview

Then we're applying those ideas to the question of why falsehoods can persist and spread even when there is strong contrary evidence available.

I have read a couple of scientific paper that claimed that the only way to change whatever, is from the top..meaning that people will listen to who is the president of their country more than anything else.. Apparently they do get the message when it's from higher sources.. I understand the influence corporations have over politics so I'm not surprised that we don't get the messages we should.

I also have noticed that mentality have changed tremendously since the beginning of globalization 30 some plus years ago...

going back to my questioning people about their daily behaviors and actions..the answers I get mostly is that they're trying to protect their jobs/job prospect (main factor why you won't find anything organic (I even wonder if this comment will get Shadow hidden just because of the mentioning of it) on reddit science)) with a hint of laziness accepting whatever they're getting fed regardless of accuracy or not... seems like part the reasons for their misbehavior is linked with the lack of governmental guidance from the Top.

What does philosophy has to say about this reasoning and how do we get out of it? and thank you for your time.

[Gallionella](#)

If you have any of the references to the papers you mention on people being more influenced by leaders or the President, I would be very interested in seeing them. My sense is that this is a pretty partisan issue right now: some people are willing to believe what President Trump says irrespective of whether it contradicts the evidence of their own senses, while others would think that if he said the sky was blue, that it must mean it's green.

In any case, one of the main things we end up arguing in the book (at least as it stands now!) is that (a) where someone sits in the network of social connections makes a big difference, with some people, including various media personalities and politicians, connected to many more people than others have an outsize influence; and (b) that people are generally more likely to change their beliefs when presented with evidence from someone who they take to have generally true beliefs already (i.e., someone who agrees with them). This means that some obvious ways of trying to combat false belief, for instance by sharing evidence more broadly and trying to increase social connections among groups that do not usually listen to one another, are unlikely to be successful: evidence from the wrong sources has the opposite effect of what one would like, and connections you can build in this way will generally be weaker. What this means is that I more or less agree with what I take to be the thrust of your comment, which is that a lot of responsibility lies with people who are already very powerful and well-connected---who often have strong personal incentives to mislead their followers.

Hi James, thank you for being here today... this just made the news

"All of our observations find a complete symmetry between matter and antimatter, which is why the universe should not actually exist," explained Christian Smorra, the author of a new study conducted at CERN. <https://cosmosmagazine.com/physics/universe-shouldn-t-exist-cern-physicists-conclude>

How does this help you in the physic of nothingness...and is it conceivable that gravity magnetism and maybe a couple other forces maybe combined in a Quantum State becomes or actually were/are matter or Quantum matter...if there is such a thing?

thank you again

[Gallionella](#)

Thanks for bringing this to my attention. I haven't read anything about it, and the link isn't working now. So I'm afraid I don't have anything to say...

What do think about Sartre?

[SilentShoegazer](#)

I read some Sartre in high school (The Flies, Nausea, maybe some others) but it never really did anything for me.

Could it be that false beliefs support an individual desired outcome but not the true outcome? So are people generally are more inclined to believe in their beliefs and desires rather than in the evidence that being presented?

Two interesting examples:

Scientific support of vaccines and general perception that there is a link to autism

Scientific support of climate change and general political circles/business denial of the evidence

[baudeagle](#)

Thanks for this. I take it you're responding to what I say above about my next book. Let me say: my co-author on that project is Cailin O'Connor (cailinmeister), and she may also weigh in on some of these questions.

The sort of phenomenon you are discussing sometimes goes under the name "motivated reasoning", which describes cases where we tend to find and prefer arguments that support the view we already hold. I think this certainly does happen, and likely very often.

But I also think that there's a huge literature on the role that individual psychology plays in our biases, blindspots, and inability to adequately synthesize evidence available to us. What Cailin and I are trying to do is to better understand whether there are effects that make it harder or less likely for us to come to believe true things that have nothing to do with individual psychology, but rather have to do with the way we share information with one another and the way we react to others' evidence. What we show is that there are mechanisms that can lead to things like persistent false belief, actions that are incompatible with your (true) beliefs, and polarization in belief even in communities where every agent is responding to evidence in a rational way.

The examples you consider are interesting to consider for just this reason. The vaccine case seems to be one where there are strongly held opinions on two sides, and not a whole lot of communication between them. On the one hand, you have a whole lot of scientists and public health experts providing epidemiological evidence that vaccines do not cause autism; and on the other hand, you have individuals claiming that their own experiences contradict that. Neither group takes the others' evidence seriously. You might think this is because the individuals are biased or stupid or ignorant. But we want to argue that it could also be that individuals are trying to conform with the actions of others in their social groups, and perhaps using their stance on vaccines to signal that they are legitimate members of those groups. (A scientist who expresses skepticism about vaccine safety would very likely be scorned by other scientists, for instance.) Another explanation is that people tend to think that other people who believe the same sorts of things as them are more likely to be telling the truth about various experiences, which means that the way evidence spreads through a network can depend on who produced the evidence and how much disagreement is present in the first place.

We also talk a lot about propaganda and the manipulation of belief. I think the example of climate change is perhaps more about industrial propaganda than the sorts of things that seem to matter in the vaccine case.