Why Science?

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This note is based on course notes used to lead a discussion of the importance of science. The discussion has been successfully used for student motivation in an introductory course in physics at the University of Toronto. There is no physics content in this note, and although the subject of physics is prominent, other areas are also discussed. There are some questions used for stimulating discussion in class, and the answers are discussed at the end. There are extensive references, indicated by numbered superscripts, if you wish to learn more.

I. Introduction

In 1600 all educated people in England† believed the following:[1]

- Witches can summon storms that sink ships at sea.
- Werewolves exist, although there happen to not be any in England. They can be found in Belgium.
- A murdered body will bleed in the presence of the murderer.
- Mice are spontaneously generated in piles of straw.
- There exists an ointment that, if rubbed on a dagger that has caused a wound, will cure that wound.
- The shape, color, and texture of a plant can be a clue to how it will work as a medicine because God designed nature to be interpreted by mankind.
- Nature abhors a vacuum.
- The earth stands still and the sun and stars turn around the earth once every twenty-four hours.
- Rainbows are a sign from God.
- Dreams predict the future, if we know how to interpret them.
- Letting blood from the patient, which balances the humors in the body, can cure most illnesses.

By about 1730 an educated person would believe **none** of these things except for the last one.‡

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† It makes no significant difference if it were someone from any other European country.
‡ We will explore the use of bloodletting later.

It is tempting to dismiss those folks from 1600 as just being stupid. However this seems wrong: there is no evidence that they were any stupider (or smarter) than we are today.

We will begin by discussing what happened beginning in about 1600.

Question 1. How could all those educated people in 1600 believe all those wrong things?

II. The Scientific Revolution

What happened beginning in about 1600 is that Galileo, Torricelli, Newton, and others invented science and the scientific method. This happened largely in Europe. Thus, although there were contributions from Persia, China, India, and elsewhere, our discussion is largely Euro-centric. Note that science is taken to be an *invention*, not a discovery. The result of the invention is often called the *Scientific Revolution*. The English poet Alexander Pope summarised the impact of the revolution nicely in 1730:[2]

> Nature and nature's laws lay hid in night:
> God said "Let Newton be" and all was light.

The scientific method involves a cycle of observation, hypothesis, and testing. Figure 1 illustrates.[3]

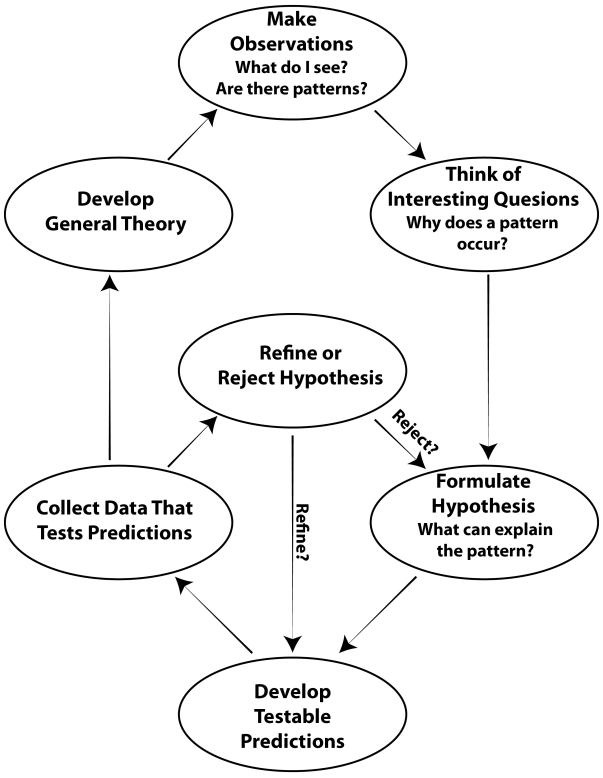

Figure 1. The Scientific Method

The invention of science was initially focused on understanding the problem of the relation between motion and force, i.e. *dynamics*. Here we will be emphasizing the nature of the scientific method that led to these advances in understanding. We will then extend the scientific method to topics beyond dynamics.

Science is based on the beliefs that:[4]

- The world is intelligible. The phenomena we experience may be explained by principles that are deeper than the phenomena themselves, and we are capable of discovering those principles.
- We must allow the world to tell us whether our ideas about it are correct. The traditional causes of belief – faith, revelation, dogma, authority, common sense – are generators of error and should be dismissed. Instead we need to let the data speak to us.

Highly influential in the invention of science was the Royal Society of London (founded in 1660), whose motto is "Nullus in Verba" or "Take nobody's word for it."[§] Instead of accepting the word of the authorities such as Aristotle, they embarked on a program of *observational experiments*.[**] The Society's coat of arms is to the right.

Figure 2. The Royal Society Coat of Arms

Here we will concentrate on *classical physics*, which is physics before the discovery of quantum mechanics in the 1920's. Classical physics makes some assumptions about the nature of the universe:

- The world is mechanistic, a "clockwork".
- It is describable by *Laws*.
- The Laws are mathematical.

Is the universe really like this? It turns out that quantum mechanics calls into question the first assumption, that the world is mechanistic. Nonetheless, we will assume that the

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[§] Including your physics professors!

[**] The Royal Society also sponsored expeditions of discovery, including the famous voyages of Captain James Cook to the South Pacific on board the HMS *Resolution* and HMS *Endeavor*. It turns out that Gene Roddenberry, the creator of *Star Trek*, was a big fan of Captain Cook. Captain Cook was the model for Captain James Kirk on the TV show, and the mission of the starship *Enterprise* was much the same as the mission of the sea ships *Resolution* and *Endeavor*.

world really is like a big machine with strict cause and effect governing its behavior. As we shall see, in our everyday life this assumption is usually very reasonable.

In 1814 Laplace nicely summarised the clockwork nature of the universe:

> We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.

Question 2. If Laplace is correct, do you have free will to decide, for example, whether to study physics tonight or instead go to the movies?

III. Extending the Scientific Method

So far, we have been discussing the scientific method in the context of dynamics. The basic method and assumptions have been extended to many other fields.

For example, another of Newton's many contributions is his Law of Gravitation. This law combined with his laws of motion allowed the first complete description of the motions of the Earth, moon, the other planets, and the stars. By now the method used is familiar to us. People have been observing the motion of celestial objects, i.e. doing *observational experiments*, for as long as there have been people. Particularly notable for this story are the data of Tycho Brahe in the late 1500's. Then in the early 1600's Johannes Kepler analysed Brahe's data and devised three rules that explained the observations of the motion of the planets. Sometimes these are called *Kepler's Laws of Planetary Motion*, although they are closer to *ad hoc rules* than full-fledged laws. Then in 1687 Newton published his Law of Universal Gravitation. This coupled with his laws of motion explained Kepler's Laws and much more, including for example, the motion of the moon around the earth.

The scientific method was also used to achieve a greater understanding of the phenomena of electricity and magnetism. Here is a brief timeline of some of these developments:[5]

> 1550 – 1600: the first truly scientific approach to the study of electricity and magnetism by William Gilbert.
>
> 1750 – 1799: Benjamin Franklin with his famous kite experiment and other forays into science extends our understanding of electricity.

1800 – 1819: Alessandro Volta invents the first primitive battery, discovering that electricity can be generated through chemical processes; scientists quickly seize on the new tool to invent electric lighting.

1820 – 1829: Hans Christian Ørsted's accidental discovery that an electrical current moves a compass needle rocks the scientific world; a spate of experiments follows, immediately leading to the first electromagnet and electric motor.

1830 – 1849: Michael Faraday produces his brilliant and enduring research into electricity and magnetism.

1850 – 1869: The Industrial Revolution is in full force. Zenobe Gramme invents the electrical generator. James Clerk Maxwell formulates his series of equations on electrodynamics, which unified the electric and magnetic interactions into a single *electromagnetic* interaction.

1870 – 1879: The telephone and first practical incandescent light bulb are invented while the word "electron" enters the scientific lexicon.

Surprisingly, one of the last holdouts against the Scientific Revolution was biology. Up until close to the middle of the 19th century biology was dominated by *vitalism*, the theory that the origin and phenomenon of life depend on some force or principle that is different from purely chemical or physical forces. Then in 1842 four young physiologists signed an oath repudiating vitalism and vowing to consider only physicochemical forces. It is called the Reymond-Brucke oath, and they signed it in blood, like pirates. As Jaynes wrote, "This was the most coherent and shrill statement of scientific materialism up to that time. And [it was] enormously influential."[6]

One of the four physiologists who signed the oath was Hermann von Helmholtz. Shortly after, he largely moved from physiology to physics, especially biological physics. Five years after signing the oath, he was one of the first to proclaim the principle of conservation of energy.

You will recall that earlier in the term we discussed a list of things all educated Europeans believed in 1600, and that by 1730 nobody believed any of them except one. The exception was the belief that letting blood from the patient can cure most illnesses. Once science was accepted as the foundation for biology and medicine, then by the 1860's Charles Bennett started collecting data that showed that bloodletting was actually harmful, at least in treating pneumonia. Subsequent studies by Louis, Pasteur, Koch, Virchow, and others used the new scientific methods for other diseases, and the use of bloodletting gradually diminished to a few select conditions.[7]

Here is final example. In the early 1900's scientific observation led to the discovery of blood groups by Landsteiner and others. It is estimated that this discovery has since saved about a billion lives.[8]

IV. The Enlightenment

> *The common sense of the eighteenth century, its grasp of the obvious facts of human suffering, and of the obvious demands of human nature on nature, acted on the world like a bath of moral cleansing.*
>
> - Alfred North Whitehead, 1925

The physical sciences are, of course, concerned with the physical world. As we have seen, the methodology of the physical sciences was largely developed in the 17th century. In the 18th century thinkers began to realize that the same process of evidence-based rational thought could be applied to social issues. This realization is called the *Enlightenment* or sometimes *The Age of Reason*. Steven Pinker describes the shift in thinking of the Enlightenment this way:

> Our [18th century] ancestors replaced dogma, tradition and authority with reason, debate, and institutions of truth-seeking. They replaced superstition and magic with science. And they shifted their values from the glory of the tribe, nation, race, class or faith toward universal human flourishing.[9]

As Kant put it in 1784: "Dare to know!"[10]

The consequences of the Enlightenment have been profound. To just choose one example, the values of the Enlightenment revolutionized the relation between the people and their government; in the case of the United States and France the revolutions were literal.

Here is a fairly recent example of how the scientific method has been extended into fields other than the physical sciences. It is from economics.

Up until about 2000, economists had a standard model of labor that assumed that labor markets were competitive, and that workers would choose to work where they were paid more. This meant that companies would only hire as many workers as made financial sense. An increase in the minimum wage that companies were required to pay their workers would make labor more expensive, which should translate into lower employment. Virtually all economists accepted at least the rough outlines of this model and the conclusion that increasing the minimum wage kills jobs. Note that the main justification for the storyline of the model is only that it seemed to make sense to the economists.

In the early 1990's David Card and Alan Krueger started collecting data on employment and increases in the minimum wage in the U.S. or in individual states in the U.S. For example, in 1994 the minimum wage in New Jersey increased from $4.25/hr to $5.05/hr, while in neighboring Pennsylvania the minimum wage was unchanged at $4.25/hr. Card and Krueger compared trends in employment in fast-food restaurants on opposite sides of the border between the two states. From this and similar "natural experiments" involving other states they concluded that increasing the minimum wage does not kill jobs. They

published their results in a seminal book, *Myth and Measurement,* in 1995.[11] The initial response was hostile: their motivation, data, and analysis were viciously attacked. Eventually, however, the attacks were shown to be baseless, their results have been replicated, and now almost all economists accept that at least moderate increases in the minimum wage do not reduce employment. So Card and Krueger's applying of the scientific method to the question of the minimum wage has changed economics and politics.

Another example of evidence-based thinking about issues beyond the physical sciences involves the field of education. Basically we have begun to learn how to apply the scientific method to the problem of how we learn. Over the past few decades experiments have been devised whose results indicate which teaching methods are effective and which are not. These results have caused a revolution in the way we teach. Led by physics (of course!), the results of the research have been widely adopted by many STEM educators, and are now spreading even more widely. In physics, the premier journal is The Physical Review, which has separate sections for different fields of physics; one of those sections is devoted to Physics Education Research (PER).[12]

V. The Industrial Revolution

The Scientific Revolution was a gift to us from the 17th century, and the Enlightenment from the 18th. The 19th century gave us something too: the Industrial Revolution. It was based on applying the results of science to how we produce the goods that we want or require, and how those goods are transported from where they are manufactured to where we wish to use them. It also began a revolution in how we communicate with each other.

For example, in §III – *Extending the Scientific Method* above we presented a brief timeline of the development of electricity and magnetism. Many of those items, such as the electric motor, electrical generator, telephone, and incandescent light bulb, could only be produced in quantity and widely distributed because of the Industrial Revolution.

The values of the Enlightenment were and continue to be important in insuring that at least some of the benefits of the Industrial Revolution are available to everybody worldwide, instead of being totally concentrated in the hands of a very few.

I began §IV – *The Enlightenment* with a quote from Whitehead. Although I like the sentiment presented in the quotation, I think his use of the phrase *common sense* is unfortunate. As Einstein said in a well-known quote, "Common sense is the collection of prejudices acquired by age eighteen."[13] In fact, common sense is related to a way of thinking that is called by the psychologists *System 1*. It is fast, intuitive, and almost instantaneous. This is different from *System 2*, which is slow, deliberative, and involves reasoning and analysis.[14] An example is walking down a sidewalk. If it is a nice day you can walk along barely paying any attention to where you are placing your feet, where your next step will be, etc.: your System 1 is in control. However if there has been an ice storm and the sidewalk is coated in a cm of ice, you are quite conscious and think

carefully about where you step: your System 2 has taken over. In terms of brain physiology, System 1 is associated with evolutionarily older regions of the brain, while System 2 occurs in more recently evolved regions.[15] We will discuss all this further below.

VI. Consequences

The scientific method, the results of science, the values of the Enlightenment, and the Industrial Revolution have combined to have a profound effect on our lives. For example, worldwide the average life expectancy has more than doubled since at least 1760. Figure 3 illustrates:[16]

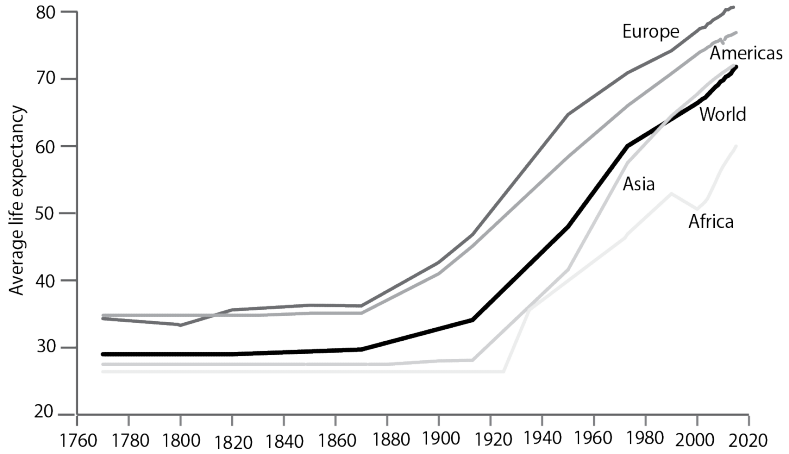

Figure 3. Historical Life Expectancy

Similarly, the fraction of children who die before reaching the age of 5 used to be between a quarter and a third. It has now plunged by a hundredfold, and the plunge has been global. Figure 4 illustrates:[17] Among the many consequences of the dramatic drop in child mortality is that parents are now having fewer children, since they no longer have to hedge their bets against losing their whole families.

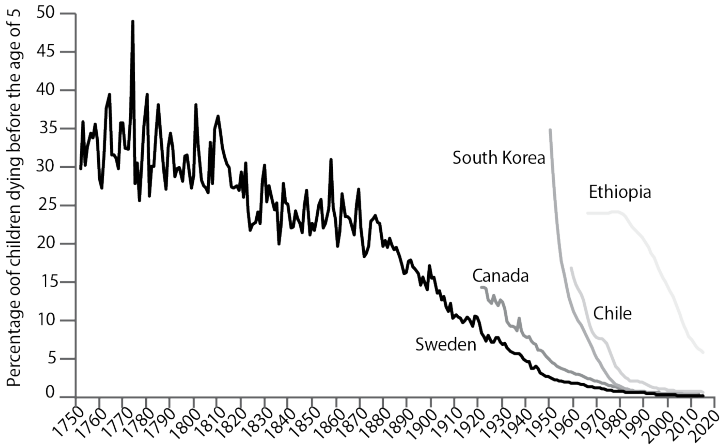

Figure 4. Historical Infant Mortality Rates.

There have been similarly dramatic advances in maternal mortality, percentage of people who are malnourished, people living in extreme poverty, literacy especially female literacy, and more.[18]

When he was U.S. President, Barack Obama said in 2016:[19]

> The world today with all its pain and all its sorrow, is more just, more democratic, more free, more tolerant, healthier, wealthier, better educated, more connected, more empathetic than ever before.
>
> If you didn't know ahead of time what your social status would be, what your race was, what your gender was or sexual orientation was, what country you were living in, and you asked what moment in history would you like to be born….. you'd choose right now.

Question 3. Do you agree with Obama?

Of course, there was and continues to be pushback against these advances.

For example, the Romantics, if I understand them, seem to think that the existential angst of a starving artist living, however briefly, in an unheated garret in Paris is somehow more *authentic*. Whatever that means.

Another example is Darwin and Wallace's 1858 theory of evolution. The fact of evolution has been confirmed by subsequent scientific studies thousands of times. Nonetheless, many have refused to accept this reality. Part of this has been due to a conflict between evolution and various religious tenets. In the U.S. denial of evolution has been particularly strong by evangelical Christians.[20] Today, 34% of Americans reject evolution entirely.[21] Canadians do considerably better: 61% of Canadians think human beings evolved from simpler life forms.[22] But before Canadians can start patting themselves on their backs, another way to state the statistic is that 39% of Canadians don't necessarily think human beings evolved from simpler life forms.

In India the higher-education minister has recently demanded that the theory of evolution be removed from school curricula because "Darwin's theory is scientifically wrong."[23] This too has religious overtones, since the current Indian government is governed by the Bharatiya Janata Party (BJP), whose policies have historically advocated Hindu nationalist positions.

One pushback against science with literally deadly consequences is the belief by some parents that vaccinating children causes autism. This is despite a huge amount of publicly available data that show that this belief is wrong.[24] The measles vaccine is estimated to have saved 120 million lives.[25] But today children are dying because their parents refused to vaccinate them. We will explore this topic further below.

Our final example involves what is almost certainly the single most difficult problem that we face today: climate change. Again the data are overwhelming that climate change is real and that human activity is a major cause. The consequences of allowing this to continue are extremely frightening. Nonetheless, in the US 14% of the people reject the existence of climate change and 34% reject the idea that it is caused by human activities.[26] Canada is hardly better: nearly a third of Canadians say they're not convinced that climate change is being caused by human activity.[27] Some of the climate deniers believe that the whole thing is a massive hoax being perpetrated by climate scientists.

VII. Scientists in Society

As scientists, or at least scientists in training, we have a particular responsibility to use our expertise to help inform debates on current social issues.

For example, vaccination rates of young children are falling, in large part because of parent's fear of a link between vaccinations and autism (ASD).[28] Here are some data from the condensed form of Ref. 24.

Table I. Four-Year Olds With and Without an Older Sibling with ASD

Older Sibling with ASD	Number of ASD Cases	Sample Size
No	460	91 648
Yes	89	1 878

It is convenient to express the rate r of ASD as the number per 100,000 people. So for kids without an older sibling with ASD the rate is:

$$r_{\text{No}} = \frac{\text{Number of ASD Cases}}{\text{Sample Size}} \times 10^5 = \frac{460}{91{,}648} \times 10^5 = 502 \tag{1}$$

As with any result of an experimental measurement, there is an associated uncertainty in the result. It is reasonable to calculate the uncertainty in the rate, Δr_{No}, to be:

$$\Delta r_{\text{No}} = \frac{\sqrt{\text{Number of ASD Cases}}}{\text{Sample Size}} \times 10^5 = 23 \tag{2}$$

so we write:

$$r_{No} = 502 \pm 23 \tag{3}$$

We similarly find that for four-year olds with a sibling with ASD the rate is:

$$r_{\text{Yes}} = 4700 \pm 500 \tag{4}$$

Clearly, there is a large correlation in ASD with having an older sibling also with ASD.

A common vaccine used with children is called MMR (mumps, measles, rubella). Here are some more data from the condensed form of Ref. 24.

Table II. Four-year Olds Without an Older Sibling with ASD

MMR Vaccination Status	Number of ASD Cases	Sample Size
1 dose	395	79 691
Unvaccinated	65	11 957

For these samples, the rate of ASD for children who have been vaccinated is:

$$r_{\text{V}} = 496 \pm 25 \tag{5}$$

and for unvaccinated children it is:

$$r_{\text{U}} = 544 \pm 67 \tag{6}$$

Note that if we ignore the uncertainties and just look at the values, then $r_{\text{V}} = 496$ and $r_{\text{U}} = 544$. So the vaccinated children have a slightly *lower* autism rate than the unvaccinated ones.

Although the *value* of r_{V} is smaller than the value r_{U}, they are the same within uncertainties. The smallest value of r_{U} consistent with its uncertainty is $544 - 67 = 477$, while the largest value of r_{V}, consistent with its uncertainty is $496 + 25 = 521$. Since $477 < 521$, there is no measured difference in autism rates.

This does not mean that the data *proves* there is no correlation, only that if such a correlation exists it is too small to be seen with this experiment.

Increasing the sample sizes would reduce the uncertainties, and perhaps show a very very small correlation. There are many other experiments on MMR and ASD, and combining all those results in what is called a *meta-analysis* has failed to show any correlation.[29]

The data for children with an older sibling with ASD, which are not shown, show similar trends.

The belief in a link between vaccinations and ASD is largely due to some fraudulent science published by Andrew Wakefield in 1998.[30] Many other non-scientists, whom I will not dignify here by naming or referencing, have propagated the belief.

But, if parents who believe in such a link and refuse to vaccinate their children are confronted with the data such as Table II, the effect is that they believe that vaccinations cause autism even more strongly!

This is worth repeating: anti-vax parents, when shown the data, cling to their belief even more.

Question 4. You are talking with a parent who believes that vaccinations cause autism. What strategy may help you change their mind?

Since the introduction of vaccinations and immunizations over 200 years ago, there has been pushback against them. As with the rejection of evolution, the pushback has religious overtones. Some evangelical Christians, for example, claim that diseases are God's punishment for our sins, and vaccinations are attempting to thwart God's will.[31] In some Muslim majority countries, particularly Afghanistan, Pakistan, and Nigeria, Muslim fundamentalists are violently resisting vaccination efforts.[32] Also, in some ultra-Orthodox Jewish communities a small number of rabbis are leading anti-vaccination movements.[33]

There is more to this story than just the tendency of us all to reject data that is in conflict with our pre-conceptions. We all have biases, and those biases can actually interfere with how we interpret data. The remainder of this section illustrates this. The discussion is based on work by Kahan, Peters, Dawson, and Slovic.[34]

Here are some **made up** data on the effectiveness of a new skin cream for a sample of poeple.

Table III. Made Up Data on a Skin Cream Effectiveness.

	Rash Improved	**Rash Got Worse**
Used New Skin Cream	223	75
Did Not Use New Skin Cream	107	21

Just from inspection we see that for people using the skin cream about three times as saw many saw an improvement compared to those who saw their rash get worse. For those who didn't use the skin cream, about five times as many people saw an improvement compared to those who saw their rash get worse.

Put another way, in terms of the total samples, about ¼ = 25% of people who used the cream saw their rashes get worse, while only about 1/6 = 16% of people who didn't use the cream saw their rashes worsen.

The conclusion is that the skin cream is not effective.

When this question was given to a large sample of people in the U.S., most of those who were *numerate*[††] could correctly answer the question provided they were prompted to think carefully about it. People who were not numerate couldn't deal with it at all.

Here are some **made up** data on gun control and crime rates for a sample of different regions.

Table IV. Made Up Data on Gun Control and the Crime Rate.

	Crime Rate Improved	**Crime Rate Got Worse**
Gun Control	223	75
No Gun Control	107	21

Note that the numbers in the table are the same as for Table III. If this data were real, then, you would conclude that gun control is not effective.

This data were presented to a large sample of people in the U.S. When given to numerate right-wing Republicans, most spotted the conclusion that no gun control was better. But most numerate left-wing Democrats missed this entirely. For the Democrats, their biases in favor of gun control made them blind to what the data indicate.

Here is another **made up** dataset on gun control and crime rates. Note that here the numbers in the two rows have been reversed from the previous dataset.

Table V. More Made Up Data on Gun Control and the Crime Rate.

	Crime Rate Improved	**Crime Rate Got Worse**
Gun Control	107	21
No Gun Control	223	75

This data were presented to another large sample of people in the U.S. When given to numerate left-wing Democrats, most spotted the conclusion that gun control was effective. But most numerate right-wing Republicans missed this. For the Republicans, their biases against gun control made them blind to what the data indicate.

Although our example of gun control is in the context of U.S. politics, the conclusion is much more general: our biases and preconceptions can dramatically impact how we analyse and interpret data.

Question 5. What can we do about biases and preconceptions influencing the way that we analyse and interpret data?

[††] *Numerate* means being able to understand and work with numbers. It is for math the same as the word *literate* is for the ability to work with written language.

VIII. Conclusions

We have seen that the invention of science and the scientific method had a profound effect on eliminating superstition in a period of just over 100 years. Applying those methods to social issues in the Enlightenment had an equally profound effect on the way that people interact with their governments, and formed a basis for evidence-based public policy still used today. Applying science to how to produce the goods and services that we wish or desire in the Industrial Revolution coupled with the values of the Enlightenment has caused a dramatic increase in the quality of life of people around the world.

However, it seems that the push-back against these advances has recently been accelerating. This is in part because of a conflict between the results of science and various religious tenets. This push-back is also fed in part by the common tendency of all of us to reject evidence that is in conflict with not only our religious beliefs but also our non-religious biases and pre-conceptions.

I close with a final example. There is no doubt that one of if not the single most important problem facing us today is the fact of climate change. Regardless of its cause, it is vital that we take measures to stop this phenomenon if we are to survive. As of this writing the most recent report of the United Nations Intergovernmental Panel on Climate Change emphasizes just how dire the situation has become.[35] Further, the 2018 Nobel Prize in economics was shared by Robert Nordhaus for his work showing that carbon taxes are an effective way to reduce our production of greenhouse gases; these gases at least contribute to global warming. And yet, many of the elected leaders of governments at various levels around the world refuse to accept these conclusions.

Question Answers

These are my answers to the questions that appear above. Your answers may be equally valid and different from mine.

QUESTION 1

An educated person in 1600 believed that Aristotle (4th century BCE) was the greatest philosopher who ever lived, and Pliny (1st century CE), Galen and Ptolemy (4th century CE) were the best authorities on biology, medicine, and astronomy respectively. And, of course, in matters of faith the authority was the Bible. Although the educated person had a few books, all these authorities' ideas were primarily communicated by contemporary authorities: the professors and priests.

For example, Aristotle in *The History of Animals* wrote that animals and plants could be spontaneously generated for certain conditions.[36] And since Aristotle was considered to be infallible, up to about 1600 educated people accepted this without question. Spontaneous generation was first put to the experimental test in the 17th century by Jan

Baptists von Helmont, William Harvey, and especially Francesco Redi, and was shown not to occur.

Question 2

If our minds are governed by the same physical-mechanical rules as the physical universe, then perhaps we do not have free will. We will return to the life sciences and the scientific method later in this document.

Someone once asked the great psychologist C.G. Jung, "Do we have free will or not?" Jung wisely replied, "Yes."

Question 3

If I got to choose things beyond just when, I would be tempted to choose being a straight white upper-class male in Victorian England, born in about 1860. But choosing 1860 for any other sexual orientation, race, class, gender, or location would give me a dramatically lower prospect of living a full and happy life. Lacking such a choice, I would choose right now.

Question 4

This is a really tough question that many smart people have been thinking about.

One thing that doesn't work is to begin with "No …". This will cause your conversation with the parent to become confrontational, and confrontation seldom if ever changes anybody's mind.

Perhaps actors trained in improvisation can point us towards an effective strategy. The art of improvisation features a dialog founded on "Yes, and" and improv. training involves lots of practice in this "game".[37] For example, here is a made-up dialog where we imagine that it is raining.

> Person A: It is a lovely day today.
> Person B: Yes, and ducks particularly like it when it rains.
> Person A: Yes, and ducks go "quack quack" when they are happy.
> Person B: Yes, and "quack" is one of my favorite sounds.
> Person A: Yes, and …

So perhaps the first thing to say to the parent is, "Yes, and the belief in vaccinations causing autism is because of some research published by Wakefield in 1998." Then maybe a conversation on this important topic can occur.

Question 5

This is at least as difficult as Question 4. Here are some possible ideas.

Earlier I wrote that we must let the data talk to us. However, for the data to communicate with us we need to listen carefully. Whenever something or someone is talking to us, it is difficult to listen and hear what it/they is/are actually saying. One aspect of the improv. "Yes, and" game is that it teaches us to listen to what the other person is saying. There are some studies that indicate that "Yes, and" type conversations such as were discussed in the "answer" to Question 4 can be effective.[38]

Another aspect of this could relate to the System 1 / System 2 ways of thinking discussed above at the end of §V – *The Industrial Revolution*. It turns out that many people have difficulty suppressing an incorrect "gut" System 1 response and engage in further System 2 reflection to find a correct answer. There are some studies that indicate this it is possible to influence people so that they are more likely to use System 2 in analyzing a situation.[39] Whether or not these methods are generally applicable is still unknown.

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References

[1] All but the last of these is from D. Wooton, *The Invention of Science: A New History of the Scientific Revolution* (Harper, 2015), pg. 1.
[2] A. Pope, "Epitaph Intended for Sir Isaac Newton," (1730).
[3] This is similar to a figure by E. Raeon, https://raeonscience.weebly.com/the-scientific-method.html (Retrieved Oct. 18, 2018). A more complete and accurate figure is Figure 1.3 of E. Etkina, G. Planinsic, and A. Ven Heuvelen, *College Physics: Explore and Apply*, 2nd ed. (Pearson, 2019), 4.
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