1 The Founding of Modern Science

Intended Learning Outcomes for Lecture 01
You should be able to do the following after this lecture.

(1) *Describe* what is science and explain the scientific method "in a nutshell", illustrating your explanation with a straightforward example.
(2) *Describe* the roles scientific observations play in the scientific method.
(3) *Explain* what are the main concerns that should be addressed when making scientific observations.
(4) *Explain* why anomalous phenomena are important for science, illustrating your explanation with some examples from the scientific revolution.
(5) In the context of the scientific revolution, *discuss* the difference between an evidence-based understanding of the natural world versus one based on authority.
(6) *Discuss* the steam engine's contribution to the Industrial Revolution and its impact on population growth in industrialized nations.

1.1 What is Science?

Hi all, welcome to the first video in this series. This lecture, which is made up of several videos, is about what science is and is a cut-down bare-bones explanation of the scientific method "in a nutshell" – which we will see illustrated with a few examples. We will take a closer look at the first step in the scientific method (again illustrated with an example) and then briefly review the founding of modern science and what one could say was a direct consequence of that – the Industrial Revolution, and it's here we'll see the beginning of mankind's dependence on fossil fuels.

I hope you have had a look through the intended learning outcomes for this lecture. They are listed right before this video, so let's get straight into addressing our first learning outcome, which is to answer the question:

"What is science actually?"

I bet most people think of science in terms of "subjects", like Chemistry, Physics, Biology, Medicine, and Pharmacy, just to name a few. But is this actually science? Knowledge in textbooks? Where did this knowledge come from anyway? Most people would say that the facts, ideas, and concepts in science textbooks is true to the best of our knowledge, but how do we know it's true? In fact, just how do we know what we currently know, at all? By answering these questions, we get closer to figuring out what science is.

1.1.1 What is Science and the Scientific Method in a Nutshell

At this point, we'll take a look at what science is from our course textbook *A Beginner's Guide to Scientific Method*. Right here in Chapter 1, page 5, we read:

> *"Science is that activity which aims to further our understanding of why things happen as they do in the natural world. It accomplishes this goal by applications of the scientific method."*

So, what exactly is the scientific method?

Our textbook goes on to explain, *"…it is the process of observing nature, isolating a facet that is not well understood, and then proposing and testing possible explanations."* **Observe. Explain. Test the explanation.**

The facts, ideas, and concepts we find in textbooks have all been put through this process. The knowledge in textbooks is really only one part of science – it's essentially the explanation part with some observations usually thrown in here and there. Rarely do we read about the rigorous testing the explanations went through. Nor do we hear much about those wrong explanations given earlier, and how testing, or experimentation, was used to eliminate them and home in on what now lies within science textbooks.

1.1.2 Science is Self-Correcting

You see, science is self-correcting.

The vast majority of the knowledge found in today's textbooks was all hard won, with multiple wrong explanations being proposed and then discarded until arriving at the current version. This may yet be undone if some new test of that understanding reveals it's lacking in some way.

This testing and refinement of our knowledge and understanding is the nature of Scientific Inquiry, the main topic of this course. The best way to understand scientific inquiry is through examples and application. The topic we've chosen to look at to gain an understanding of scientific inquiry is perhaps the single most important problem facing our species today – that is, climate change and loss of biodiversity. It is science that offers us our best chance at figuring out how we can get out of this mess – and what all of us need to do to get there.

OK, before we get into this serious problem, we need to get a good understanding of this "**observe, explain, test**" approach to knowledge discovery.

Did you know that any time you troubleshoot something you're actually applying the scientific method? For example, let's take a look at troubleshooting a laptop that doesn't bootup in our next video.

1.2 A PC Won't Work

1.2.1 Troubleshooting a Laptop

We find that our laptop doesn't boot, so we troubleshoot it, which is an example of a straightforward application of the scientific method.

Observation	Laptop doesn't boot
Explanation	Battery dead
Test the explanation	Plug in external power
Result of test	Laptop seems to boot, so the battery must have been dead

But now there's a new problem.

Re-running through our "observe, explain, test" steps again we find:

Observation	Laptop seems to boot, but there's nothing on the screen
Explanation	Laptop monitor not working
Test the explanation	Try connecting the external monitor with HDMI cable 1
Result of test	Laptop seems to boot, but there's nothing on the screen. (a) Either the graphics card or motherboard has issues, or (b) Something was wrong with our test.

Perhaps there is something wrong with our test. The external monitor clearly worked because we used the external monitor before conducting this test, albeit with a different cable, and it worked! We change our HDMI cable and retry the "Test the explanation" step below.

Observation	Laptop seems boot, but there's nothing on the screen
Explanation	Laptop monitor not working
Test the explanation	Try connecting the external monitor with HDMI cable 2
Result of test	Laptop definitely boots and the external monitor shows the start screen.

After performing a series of tests in the "real world", that is, by testing our explanations, we discover the following things we didn't know before performing any tests:

We had a dead battery.

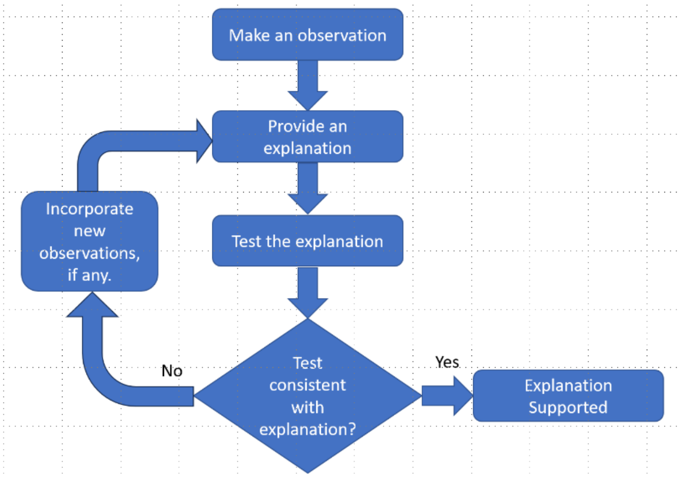
The graphics card and motherboard are working fine.

The laptop's monitor doesn't work.
A bad connection?
Screen broken?

We have a faulty HDMI cable.

1.2.2 Troubleshooting and the Scientific Method

Troubleshooting is an example of the scientific method. It is in a sense a trivial example of it – the scientific method is a lot more powerful than that. The scientific method can be used to probe and discover brand new things about nature. This, of course, relies on our explanations and then testing those explanations. If our explanation ends up not being falsified, then we have support for our explanation and the more we test our explanation the more confidence we have that our explanation is, in fact, true.



This is how things are discovered using the scientific method, and this is the way we have discovered many things about the world today. All the content in science textbooks have been subjected to this procedure. This example illustrates how science is self-correcting, where our steps taken above can be summarized in the following flow chart.

We also note that every time we loop through this chart, regardless of whether the test is consistent with the explanation or not, we gain new information about the world around us.

1.3 Teabag Experiment

In the previous video, we saw that troubleshooting a laptop was an example of the scientific method. In fact, troubleshooting anything in general represents an application of the scientific method. You observe that there is clearly something wrong. You come up with possible explanations as to what might be the cause of the problem. Finally, you go through the process of checking if the thing you thought might be wrong is indeed the cause of the problem. If it isn't then you try something else, i.e., you toss aside your previous explanation of what the problem was and make a new explanation for the cause. You continue doing this until you can at least narrow down what's the cause of the problem.

Observe, explain, and test the explanation – the scientific method in a nutshell. The point is by running through this process you will discover things you didn't know before. Now I'll illustrate this again, but in the household environment. This time we'll use the scientific method to discover something new about nature, or at least something that might be new to you.

Observations	(1) Tea bag bloats and floats on top of the water when boiling water is poured directly on top of it. (2) Tea bag doesn't bloat and sinks in the water when boiling water is poured on the side and **not** directly onto it.
Explanation	Water poured on top of the tea bag fills the pores of the teabag itself, trapping any gas inside before it can escape. The hot water heats the trapped air, causing it to expand. The trapped air prevents the tea bag from being dunked.  *Pores of the tea bag can get sealed up with water and prevent air from escaping.*
Test the explanation	Quickly seal the tea bag in cold water, trapping the air, then pour boiling water near to but not directly onto it.
Result of test	Tea bag bloats and floats on top of the water supporting the explanation.

The test *supports* our explanation, rather than confirm it. If we really wanted to check whether this explanation is correct, we would need to do a lot more tests. Compared to troubleshooting the laptop in the previous section, the results of the test with the tea bag are a lot more tentative since we generally know more about the way a laptop works and our tests are more directly indicative of the explanation being correct (or not) than the tea bag. We don't know that much about what's going on exactly. We have this speculative explanation that water is somehow filling up pores, sealing that tea bag, and our test *is* supportive of this explanation. But ideally, we would find out a lot more about this phenomenon before we can say for sure that this explanation is correct.

There are lots of additional interesting questions we can now ask about this phenomenon of liquid water stretching across tiny gaps in the teabag and effectively sealing the air inside:

- If there really is water sealing the pores, then can we see it?
- How thick is the film of water sealing the pores of the teabag?
- How long does this film last?
- How strongly does the water seal in the air? i.e., what level of air pressure is needed to break the seal?
- How big do the pores need to be so that the water can't seal air inside them?
- Does adding other substances to the water change this behavior?
- What about other liquids? Do they behave in the same way?

In science, answering one question often leads to more questions, and an investigation can sometimes take wild and unanticipated twists and turns that lead to new knowledge and understanding of nature.

1.4 Cadaverous Poisoning

You may not have realized it, but in the previous video we were just starting to scratch the surface of two entire branches of science: "Interface Science" and "Colloidal Science" – extremely important areas within chemistry, food science, biology, and physics, etc. A good understanding of these areas is also of great importance to industry and for most of the products industry produces.

1.4.1 Semmelweis and Childbed Fever

I have one last example of a fairly straightforward application of the scientific method, taken from our textbook and drawn from the annals of science. Our example will be from the area of medicine and we're going to wind the clock back to 1846, to a time when science had yet to discover the "germ" – that is, those nasty little disease-causing organisms so small they are invisible to the naked eye.

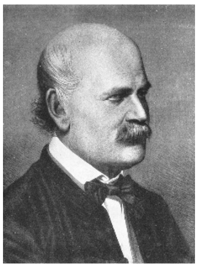


Figure 1
Semmelweis from Wikimedia: Jenő Doby, Public domain, via Wikimedia Commons

Dr. Ignaz Semmelweis (Figure 1) was hired on a three-year contract into the Vienna General Hospital's maternity clinic from 1846 – 1849. At the time "childbed fever", aka puerperal fever, was running rampant in hospitals all over Europe and the US. This disease affected mothers after they gave birth or had a miscarriage. Without going into details, it was a particularly nasty disease with a number of easily recognizable signs and symptoms.

It usually occurred after the first 24 hours and within the first ten days following delivery. The fever was deadly, killing up to 80% of those diagnosed and sometimes reached as high as 40% of all mothers admitted to the hospital. As with all physicians, Dr. Semmelweis was particularly concerned, so he studied the data on mortality rates within his hospital dating from 1841 – 1846 looking for something, anything, that might give a clue on how to stop the fever.

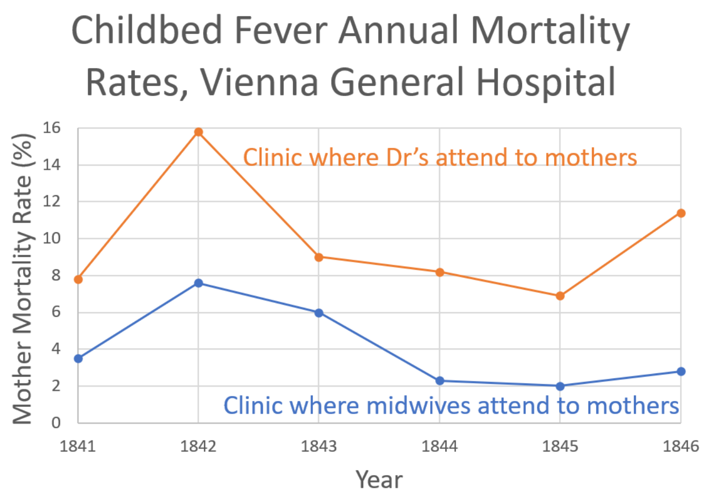


Figure 2 Mortality rates in two clinics in the Vienna General Hospital from 1841 - 1846.

He noticed something when comparing the mortality rates between two different clinics in his hospital (Figure 2). Now there was no obvious difference between the two sets of mothers in each clinic, so why were a lot more women dying in his clinic where doctors attended to mothers (orange curve in Figure 2)?

He showed the findings to his colleagues, but everyone was at a loss as to why this should be so. Was it something the doctors were doing wrong? or perhaps something the midwives were doing right? Maybe it was due to a difference in the clinical environments? Perhaps the patients in his clinic were somehow more prone to illness?

At this time, in the middle of the 19th century, the "germ" or pathogen, was not known to be the cause of disease. Germs had not been observed, and any speculation of their possible existence was not taken seriously. The reining theories for how disease was spread, caused, and treated at the time were quite wrong.

1.4.2 A Key Observation

Figure 3 Kolletschka from Wikimedia: *Unknown author, Public domain, via Wikimedia Commons*

Then a rather unfortunate incident occurred in 1847 in an anatomical pathology lab. Dr Semmelweis' friend, who he greatly admired, died after being accidentally pricked by a scalpel being used by a student doctor while he was assisting in performing an autopsy. Professor Kolletschka (Figure 3) suffered identical signs and symptoms as the mothers who died of childbed fever. Dr Semmelweis wrote about the incident:

"Day and night I was haunted by the image of Kolletschka's disease and was forced to recognize, ever more decisively, that the disease from which Kolletschka died was identical to that from which so many maternity patients died."

There is another very pertinent fact, or observation, in this case. Right after the student doctors attended the anatomical pathology lab, where they dissected badly infected corpses, they would go to Dr Semmelweis' maternity clinic to assist in the births of expectant mothers.

Do remember that the way disease was spread, caused, and treated in those days was completely misunderstood. No one knew about germs, so there certainly were no antibiotics and there was no disinfecting of anything – no hand washing of one's hands especially when, by just looking at them, they were quite obviously clean.

So now we have our careful observations, or facts,

(1) The mortality rate of mothers due to childbed fever in a clinic attended by doctors was, on average, five times higher than what appears to be a similar clinic with similar mothers but attended by midwives instead of doctors.
(2) Doctors attend to mothers in the clinic directly after having been engaged in autopsies of infected corpses in the anatomical pathology lab.
(3) A doctor dies from identical signs and symptoms to childbed fever after having been stuck with a scalpel used to dissect infected corpses in the anatomical pathology lab.

1.4.3 A Possible Explanation

Following the scientific method: observation, explanation, testing, what could be a possible explanation for these observations? Semmelweis felt that the only sensible explanation must have something to do with the corpses. Something unseen. He called this something “cadaver matter”, so he speculated that invisible cadaver matter was picked up by the student doctors touching corpses while working in the anatomical pathology lab. This matter wasn’t visible to the naked eye, but it was deadly if it entered the body via a wound. When these same doctors assisted mothers while giving birth, they transferred it to them through the usual wounds suffered during such a process.

1.4.4 Testing the Explanation

At the moment, this explanation is pure speculation. It could certainly be wrong, with some other unknown explanation being the right one. Following the scientific method, he needed a means of testing this proposal to see if he was indeed wrong. If his explanation was right, and cadaver matter existed, he decided that, quite obviously, it needed to be removed from the student’s hands before attending to the mothers in his maternity clinic.

Therefore, he instituted a policy of using a solution of chlorinated lime (calcium hypochlorite, or swimming pool chemical in water) for washing hands between autopsy work and the examination of patients. He chose this chemical because he found that the same solution worked best to remove the putrid smell of infected autopsy tissue.

Now if his explanation was correct and the chlorinated lime solution was effective, then the mortality rates of childbed fever should drop to the same levels as the midwife’s clinic or lower. Despite some resistance to the hand washing, and whispers that he had instituted a waste-of-time hand washing for crazy reasons (like a theory that corpse particles could turn the living into a corpse!), the mortality rates in his clinic dropped remarkably, as shown in the following graph.

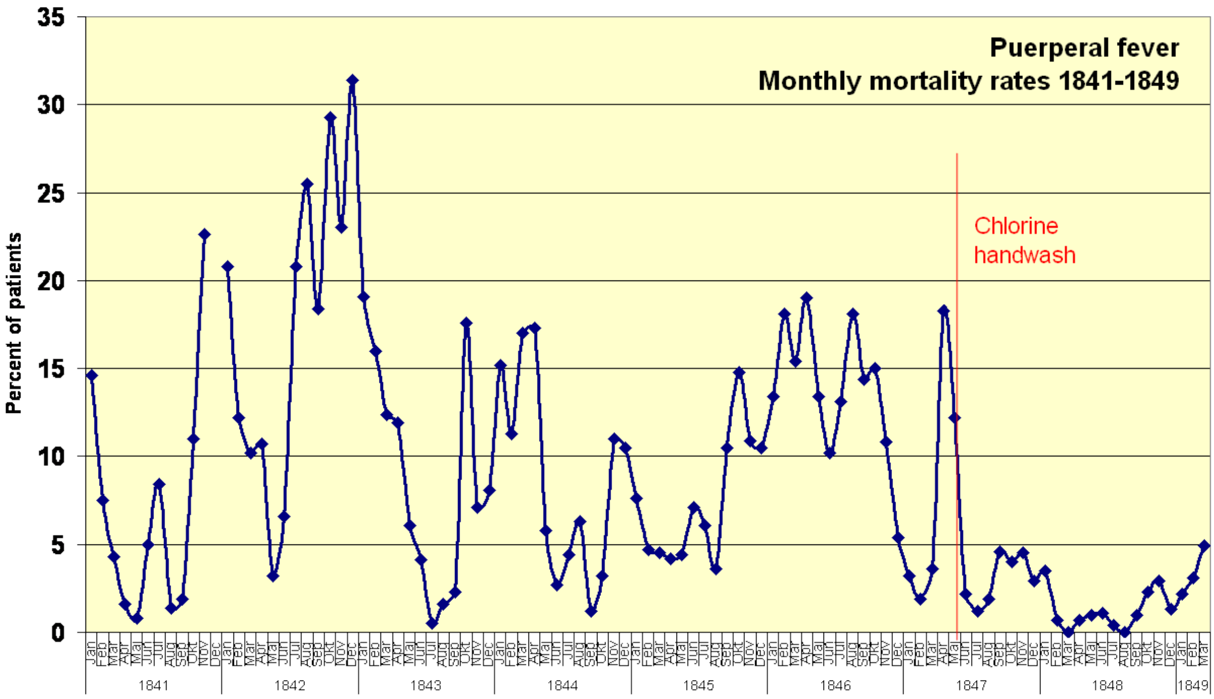


Figure 4 [Monthly Mortality Rates 1841-1849 from Wikimedia](): Power.corrupts, Public domain, via Wikimedia Commons

If you'd like to read more about Dr. Semmelweis and this interesting case, just follow the link in the box below.

https://en.wikipedia.org/wiki/Ignaz_Semmelweis

1.4.5 In Conclusion

To summarize, Dr. Semmelweis made observations and provided an explanation for those observations. Based on that explanation, he performed a test of it with the results supporting his explanation. Of course, there was no explanation of what was "cadaver matter". Furthermore, since his explanation ran against the generally accepted scientific theories of the time and it wasn't completely accepted until 30 years later when the cadaver matter was actually discovered by Louis Pasteur in 1879. A revolutionary new theory of disease was then established which remains as the prevailing explanation for diseases to date – germ theory.

1.5 Observation

Now that we have a handle on what science is and an overview of the scientific method, let's address our second intended learning outcome for this lecture, which focuses on the first step of the scientific method – "scientific observation". Observation is absolutely critical to conducting any kind of scientific inquiry. In fact, without any observations, or experiments – which are just observations themselves – the inquiry isn't even considered scientific!

Observation fulfills the following crucial roles in any scientific inquiry:

1. To identify and focus on the relevant facts about the phenomena under investigation.
2. Provide clues as to what might explain the phenomena – this one's really important if the phenomenon you're investigating is really mysterious.
3. Provide the evidence by which we can determine whether various explanations succeed or fail.

However, making useful observations can sometimes be tricky. For example, we might not know which data will be relevant to the solution to the problem at hand. Even if this is known, we can run into trouble just gathering the necessary data in the first place!

The second chapter of our textbook discusses everything we need to know about making useful observations. I suggest you read it in combination with this lecture. The chapter has several accessible real-life examples illustrating five main concerns that need to be addressed when making useful scientific observations. Pay close attention to the "Concept Quiz" on page 25 and try and answer the 9 questions asked there. In fact, I've given you a head start by answering the first question for you here.

To illustrate most of these five concerns, we'll use an important example from one of the greatest scientific minds that ever lived. This scientist was a pioneer of the scientific method and instrumental in ushering in a permanent change in the way in which knowledge and understanding of nature were acquired. The next video will show how the one and only Galileo Galilei figured out the law of inertia, which Newton later incorporated into his first law of motion.

It's important to note here that it's *not* the actual law of motion we are particularly concerned with – I won't be asking you to do any problems using it. What we're interested in in our next video is **how** Galileo worked it out from his observations of motion.

In particular, how he addressed the following concerns when making his observations:

1. Do we have a clear sense of what the relevant phenomena are?
2. Have we found a way to ensure we have not overlooked anything in the process of making our observations?
3. Do we know for sure what is based on fact and what on conjecture or assumption?
4. Have our observations been contaminated by expectation or beliefs?
5. "Have we considered any necessary comparative information?"

The 5th concern is – "Have we considered any necessary comparative information?" We have already seen a nice example of this through the observations made by Dr. Semmelweis. You should be able to recall what those comparative observations were and why they were critical to his investigation.