

MicroChat: Elements of critical thinking

Correlation and causality (Kenneth Timmis and Lara Amorim)



Cindy-Lou Ximena is the girl at the bottom of the image, whereas Jess is the boy in the centre and Kate is on the right. Timmy is the father of Scamp, the dog kissing Kate (image created by Fran Jebok; <https://www.theabsurdmicrobe.com/recurring-characters/>)

Cindy-Lou: Hello Farmer Giles, how are your sheep today?

Farmer Giles: Mornin' Ximena! (Farmer Giles has always called Cindy-Lou Ximena because he loves the name after seeing the movie El Cid and cannot understand for the life of him, why everyone else calls her Cindy-Lou!) Oh, they are just fine, now that Timmy managed to herd them together and get them away from the river and back into their field. Sheep can sometimes be rather adventurous and get into trouble, like some children I know.

Cindy-Lou, *scratching Timmy behind the ears:* will you be going to the School Sports Day in just over 2 weeks' time? I'll be in the 800 meters final.

Farmer Giles: Oh yes, I'll definitely be there to cheer you on! I believe that Jess will also be competing, and my granddaughter, Maisy, will be in the high jump. So I think my support will be needed on multiple fronts. Maisy has a good chance because she can jump like a cricket!

Cindy-Lou: Well, you should tell her mum to buy her some energy drinks to help her win! I am going to ask my mum to do the same!

Farmer Giles: And why, pray tell me, do you need expensive energy drinks to compete?

Cindy-Lou: Well, the last couple of times I ran, I drank them and won my heats!

Farmer Giles: Okay! Of course I am really proud of you, as I know your mum is, and know you are going to be a super athlete and a credit to your school. But the fact is: being a super athlete is all about body and mind: body in terms of muscle to give you speed and staying power, and the rest of it to support the muscles and give you things like energy and agility. And the mind because the mind controls the body and having a healthy attitude to sport and competition is crucial to performing well and consistently. Without taking care of body and mind, the best energy drinks in the world won't help you win. And there is concern that energy drinks may not be good for children (<https://www.hsph.harvard.edu/nutritionsource/energy-drinks/>).

Cindy-Lou, *screwing up her face which Timmy then licks because she has stopped scratching behind his ears:* But they did in the heats!

Farmer Giles: No, you think that, because you drank them and won, they were the reason you won. But I could just as easily think of other parameters of those days and make the same conclusion. For example: that you were wearing blue shorts, or the weather was cloudy, or you had muesli for breakfast, or you took your Timmy for a walk before the race, or perhaps even the fact that you managed to finish your essay on time. All of these possibilities would be correlated with your wins but had no role at all in your success. Same thing for the energy drinks. All these things are correlated with your wins but did not cause them. It is really important in life to know the difference between correlation and causality, and to distinguish between them!

Cindy-Lou: Well, actually I was wearing blue shorts.....But how do you know that the energy drinks did not help me win?

Farmer Giles: Ximena, my girl, I have to turn the question around and ask you: how do you know for sure that the drinks did help you win? *What is the evidence?*

Cindy-Lou, *with a puzzled look on her face, distractedly starts to scratch Timmy again:* erm, well the advertising on television says so, and also I saw on social media that it works. My friends all use energy drinks, and when I tried it, it worked, so it must be true.

Farmer Giles: Ahh: I see now I have some work to do to straighten you out. Firstly, advertisements on television are not the most reliable sources of evidence. They are there to increase sales, to persuade you to buy their products. They do this by telling you what you want to hear, not necessarily what you should hear. So, although advertisements can be useful in making you aware of things that you might need, you should always make up your own mind about how good they are by comparing them with the product you usually use. In this case, a drink of water. The same thing for social media and what your friends think and do.

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You really need to make your own mind up about things on the basis of good evidence, and not base your opinions on those of others.

Cindy-Lou: But if all the others have energy drinks before the race, I'll be at such a disadvantage!

Farmer Giles: No, not at all! In fact, seeing you running the other day, I am convinced you will win. And after you do, imagine the look on the faces of the others when you tell them you did it without an energy drink! You will become an ambassador of evidence-based decisions in your school, which I am sure will please both the teachers and the poor mothers who are continually pestered to buy energy drinks!

Cindy-Lou: But how can I know for sure that an energy drink won't give me a big advantage?

Farmer Giles: Evidence! Tell you what: let's do together what scientists do: carry out an experiment and gather evidence. Let's plan for you to do practice runs every day after school when Timmy and I have finished work. I'll buy some energy drinks for you and, each day, we will decide what you drink by a simple random method – we flip a coin. Heads: water; tails: energy drink. Because you can probably tell immediately by taste, we can't make this properly "blind", but we can still try to keep expectations from steering the result: we'll use the same sports bottle each day and add the same splash of lemon flavour to both drinks so they taste more alike, and we won't talk about your times until the end of the 10 days. The water is what scientists call the control. I will time your runs each day and, after 10 days, we will compare your speeds and see if there is a difference between the control and the energy drink run speeds.

Cindy-Lou, *looking bright and scratching Timmy a bit too energetically:* Gosh! when my friends see you at the track timing me with a stopwatch they will be impressed!

Farmer Giles: They most certainly will, and will also undoubtedly want to know what we are up to. Which is good because they may also start to think about experimenting and gathering evidence about issues that concern them, or at least trying to find evidence others have obtained.

But our experiment would not be accepted by scientists because it is still very simple: there are variables other than the energy drink that can influence your speeds, such as wind, rain, how late you stayed up the night before chatting with your friends or looking at social media, whether or not you had a good day at school, and even the fact that you will probably get faster over the days of the experiment simply because you are training. That is why we try to keep your routine the same each day (same warm-up, same time of the day, same track) and why we jot down a couple of quick notes like sleep and weather. Nevertheless, even though it is a simple, crude experiment, it may tell you if energy drinks make a big difference.

Cindy-Lou: Well, I personally think it will give us the answer!

Farmer Giles: Scientists would disagree with you, because they spend their lives trying to obtain evidence that can help them advance in their search for the truth. If they would just accept a hint about something before going on to the next stage, they would be perpetually chasing clouds.

For example, in relation to your energy drink and its real effects: there has been quite a bit of excitement recently about how our tummy microbes may influence our wellbeing. A lot of really

well done experiments indicate that they may be very important in preventing disease and even may affect our mental health.

Cindy-Lou: Oh yes, I have heard about how our gut microbes can affect our moods: I always tell Jess, when I am in a bad mood because a friend did not give me a heart on social media, and won't help him clean the dishes after supper, that it is the fault of my gut microbiome!

Farmer Giles: Hhmm... Anyway, an important way scientists obtain evidence for causality is through randomised (decided by chance, like flipping a coin), double blind (so people don't know which treatment they're getting), studies with placebos (a "pretend" treatment that looks the same). This is easy to understand. Imagine you have discovered a microbe – let's call it *Ximenias* – that you think will make my wheat grow faster and produce more and better grain. You and the government are very excited because, if you are right, it will reduce food costs, increase food security and reduce the amount of land needed for wheat production, freeing up land for other crops, which will also increase food security.

But: excitement is not enough – convincing evidence is needed. So you recruit me and my farm to obtain this evidence. You, me and a good statistician – an expert in statistics – who will help us design the experiment and analyse the results afterwards, sit together with strong cups of tea and plan the experiment. The experiment is basically quite simple: we just need to compare wheat growing with and without *Ximenias*. However, applying *Ximenias* – say by spraying – introduces a treatment variable, the spray, so we control for this with something called a placebo – a spray that does not have *Ximenias* in it. So the experiment consists of two plots: one sprayed with a solution containing *Ximenias* and another sprayed with an almost identical solution but lacking *Ximenias*. So we create two plots on my field, sow the wheat seeds, carry out the treatments, wait for the harvest and then compare the yields. Simple, no?

However, in practice it is a bit more complicated than that because of two issues: reproducibility (would we get a similar result if we repeated it?) and controlling for other variables. Reproducibility is simply an issue of increasing the number of plots so that the statistician can judge how much natural variability in yields there is from plot to plot. In other words: if yields naturally vary by 10%, and if we see a 8% higher yield in the plot treated with *Ximenias*, *Ximenias* is obviously not as good as you thought it was. So, instead of 2 plots, our statistician friend may tell us we need 8.

Then there is the issue of controlling for variables. For example, the field we will use may not be completely flat, so some parts may get more sun than others, some parts may be better drained than others so plants will have different amounts of water, etc., etc. To deal with this, we need more plots so that each of our treatments is carried out over the whole range of possible environmental variables. Our friend may therefore tell us we need not 8 plots but 48! Moreover, we need to make sure that there is no spill-over of *Ximenias* treatment to control plots, so we may need some space between plots.

And now comes the magic of our statistician: to avoid any bias in our experimental design, for example having too many plots enjoying higher sunshine for treatment with *Ximenias*, she "randomises" (assigns by chance) the treatments among the plots. However, there is one more variable to control, namely any possible bias of the people carrying out the experiment. To do

this, the treatments are “blinded”, that is: we do not know which plots receives *Ximenias* and which plots received the placebo, until after we have measured the plot yields.

Now: if after all this, the result is that wheat yields from plots with *Ximenias* are 65% higher than yields from the placebo, and the natural variation is 10%, we can be confident that this experiment clearly shows that *Ximenias* works well. We are very happy and celebrate with a strong cup of tea and a piece of your mum’s carrot cake.

However, we can never be sure about something from a single experiment, under a single set of conditions, so we need to repeat it next year, in a bigger experiment on fields with different soil types, environmental and climatic conditions. And, if all goes well, the following year we need to repeat the experiment on other farms in other countries, so that we can see how good *Ximenias* is under all types of farming conditions. If it continues to be successful, we are continually progressing from correlation to causality and ultimately can be confident that increased plant growth is specifically due to treatment with *Ximenias*.

Cindy-Lou: Golly! Showing that something really works is a really complicated business!

Farmer Giles: It most certainly is, and for good reason. There are quite a few black sheep out there who just want your money and will do anything to get it. A typical way is to tell you that they have a product you can buy that does something you want and list statements of people who have tried it and found it to work. Of course, perhaps these people do not exist or, if they do, they are paid to say what they say. But, even if they are not paid, they may not be representative, i.e. they have been selected by the company as having had positive experiences while ignoring those who did not. Independent studies of the type I just described is the only way to have confidence in a new product.

And some products can really harm us, which is why well-designed independent studies are essential. Studies on products for humans, rather than for plants, even go a step further to eliminate bias: the so-called double-blind study. In this case, neither the persons carrying out the study, nor the people who receive the product know who is receiving what product. Both the treatments and the recipients are coded – the recipients are not identified by name but by code – and only when all results have been recorded is the code broken for analysis. Randomised, double-blind trials are essential for demonstration of causality and are the foundation of assessment of the utility of new medicines.

Cindy-Lou: Oh: I now see why new medicines are so expensive. So....you think I should not bother with energy drinks.....

Farmer Giles: Definitely not! And, imagine if, as I expect, you win the race, you will know that you did it all by yourself, without any help from a product that anyone, and in particular your competitors, can buy!

Cindy-Lou: Well, as mum says, in the end the main thing is to do my best. If I win, I’ll be happy and celebrate with family and friends like you. And, if not, Scamp and Timmy will console me, won’t you Timmy (Timmy wagging his tail in agreement!)?

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Farmer Giles: That's the spirit! And always remember: *decisions in life should never be based on correlations, only on causalities and good evidence.*

And now you need to get off to school, and Timmy needs to earn his living and the nice bone I have for his lunch, that never fails to put him in a good mood, which the sheep really appreciate!

Class exercise

Experiments are usually designed to test a hypothesis. In science we rarely say “proven forever”; we say the evidence becomes stronger as a hypothesis survives many tests, and weaker if tests fail. The hypothesis we make here is: ***Ximenias* treatment improves wheat crop yields.**

1. On a large sheet of paper draw one of farmer Giles' fields. It probably won't be square. One side will have a road as a boundary. This boundary will also have a hedge with a few trees dotted along it and a ditch to drain water off the field when it rains. Maybe another edge also has a hedge. How does Farmer Giles enter his field with his tractor? Perhaps via a gate from the road? Perhaps there will also be another gate somewhere on another side. Let's assume the field is not totally flat and has a slope. Draw a line from the highest to the lowest points to indicate the slope. How do you think he ploughs the field? Draw the tractor imprints. Which way is North? *Randomisation:* divide the field up into 24 experimental plots and number them randomly 1 to 24 (e.g. each pupil is responsible for selecting a number and putting it on a random plot). Plots 1-12 will theoretically be treated with *Ximenias* – the TEST plots – whereas plots 13-24 will be treated with water – the CONTROL plots. To make the randomisation more tangible, you can assign TEST/CONTROL by shuffling 24 cards (12 saying TEST and 12 saying CONTROL) and placing one card on each plot. For a better “blinding”, you can label the cards A and B and only reveal at the end which letter was *Ximenias*. Wheat yields per plot are given in bushels of wheat (a bushel is 60 pounds or 27 kg). *Blinding (sort of):* each pupil should randomly select a number of bushels of wheat between 7 and 13 and randomly assign it to any plot still lacking a yield. *Note: because these yields are randomly invented numbers, you may see “patterns” or “trends” that are purely due to chance – spotting false signals is part of critical thinking.*

Now: look at the results of all the plots and answer the following questions and wheat yields:

- a. Do plots treated with *Ximenias* on average have higher yields? Calculate the mean yield of the TEST plots and the mean yield of the CONTROL plots, and the difference (TEST minus CONTROL). If there is no clear difference, we have not supported the hypothesis (and may have disproved it in this made-up dataset).
- b. Are there any detectable trends, for example higher/lower yields correlating with direction (e.g. those facing more South or West and receiving more sunshine), openness (not shaded by trees/hedges), drainage (plots at higher elevation or near a ditch), soil compaction (plots associated with more tractor traffic than others), etc?

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2. Do these preliminary results suggest something relevant to our hypothesis about *Ximenias*, or otherwise interesting? If so, what hypothesis might we propose and how would we experimentally test it?
3. Discuss how the experiment might have been better designed.