Logic is the beginning of wisdom … not the end: using Star Trek to teach scientific thinking.

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“Logic is the beginning of wisdom … not the end”: Using *Star Trek* to Teach Scientific Thinking

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Abstract

To paraphrase Batman: “[humans] are a superstitious and cowardly lot”. We cling to our preconceptions against all evidence, literally unable to see the unexpected forest when we find that our field of view is crowded with an unanticipated number of trees. Our preconceptions and other cognitive biases weaken our individual ability to perceive the world around us. Telling fact from fantasy requires cooperation and formal, unintuitive thought. Scientific thinking may be the single greatest intellectual tool ever developed. Contrary to popular belief, it is not a way of proving things true, but a way of proving them false. It is not the work of a singular intellect, but a social activity. It is a method of altering the inherent iterative cycles of bias reinforcement and leaps of faith that we consider intuitive thinking, so that we explicitly define the weaknesses in our own ideas and count on others to help us find the flaws we’ve missed. But how does one teach this unintuitive style of thinking? How do we keep our students from exchanging one set of preconceptions and cognitive shortcuts for another? Personally, I use mental models with which they are already familiar. Personally, I use *Star Trek*.

Keywords

Anthropology-based computing (ABC); Cognitive biases; Human-computer interaction (HCI); Research methods; Scientific thinking; *Star Trek*

Editors' Log: Chapter 15

The decision-making process common to the original *Star Trek* series, and to most of those that followed, was deliberately confrontational. The senior officer asks for opinions, and then a debate (or argument) ensues. John NA Brown is a specialist in how humans interact with one another and with their simple or complex tools. He asserts that these exchanges reflect the processes required in scientific thinking – a form of teamwork that might be the single greatest gift that the human race can offer to its own future. (**Eds.**)

Star Trek: The Motion Picture **(1979)**
Kirk: *Opinion, Mister Spock?*
Spock: *Recommend we proceed, Captain.*
Kirk: *Mister Decker?*
Decker: *I advise caution, Captain, we can't withstand another attack.*
Kirk: *That thing is twenty hours away from Earth. We know nothing about it yet.*
Decker: *That's precisely the point. We don't know what it will do. Moving into that Cloud, at this time, is an unwarranted gamble.*
Kirk: *How do you define 'unwarranted'?*
Decker: *You asked my opinion, sir.*
Kirk: *Viewer, standard ahead. ...Navigator, maintain course. Helmsman, ...steady as she goes.*

Star Trek: The Next Generation**, 01×06, "Where No One Has Gone Before" (1987)**
Picard: *Comment is invited. Counsellor?*
Troi: *He's convinced he's right. I have no doubt of that.*
Worf: *Captain, can you allow a man who has made one mistake back into a position where he may make another?*
La Forge: *Captain, what are our options really? I mean, if this guy can't get us back, who will?*
Data: *Captain, we're here. Why not avail ourselves of this opportunity for study? There is a giant protostar here in the process of forming. No other vessel has been out this far.*
Picard: *Spoken like a true Starfleet graduate. It is tempting, eh, Number One?*
Riker: *Aye, sir, it is. But as they say, sir, you're the Captain.*

Part of the fundamental story-telling structure of *Star Trek* is to show extremely capable people solving a problem by working together. The stories depend on the concept that, even though each individual crew member is an expert in their own right, they succeed not by reacting impulsively, but through cooperation. Even when they come from different backgrounds, professions, and fields of study, even when their entire perspective is contradictory, their heterogeneous perspectives help them find new solutions.[1]

This is reflected in the Vulcan philosophy of Infinite Diversity through Infinite Combinations [1]. This is also reflected in the formal process of scientific thinking, which teaches us that ideas and insights can be intuited, but that beliefs must be tested and confirmed by others in order to be valid. This sounds very formal, but it can be expressed more simply. The great physicist Richard Feynman said: "Science is the belief in the ignorance of experts" [2, p. 313–320]. This doubt of the knowledge of others must begin with a belief that we, our individual selves, are ignorant, too.

> This is not a new idea; this is the idea of the age of reason. This is the philosophy that guided the men who made the democracy that we live under. The idea that no one really knew how to run a government led to the idea that we should arrange a system by which new ideas could be developed, tried out, tossed out, more new ideas brought in; a trial and error system. This method was a result of the fact that science was already showing itself to be a successful venture at the end of the 18th century. Even then it was clear to socially minded people that the openness of the possibilities was an opportunity, and that doubt and discussion were essential to progress into the unknown. If we want to solve a problem that we have never solved before, we must leave the door to the unknown ajar. [3, p. 15]

The reason we must learn to doubt ourselves is that we are not actually very good at observing the world or even, contrary to our species-centric vanity, at thinking rationally about it. In fact, what we are very good at is jumping to conclusions, pretending we know more than we really do, and trying to convince ourselves that we were right all along. Let's take a look at just how and why our minds work that way.

Spock: "We have here an unusual opportunity to appraise the human mind..."
The Enemy Within

The process of thinking is not straightforward. A lot of my teaching and most of my research is based on this idea, and I'd like to take a moment to explain it to you before we go on.

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[1] This observation stands for the entire corpus of *Star Trek* (television, films, animation, and novels, until the franchise was rebooted as a film series in 2009. Prior to that, each adventure would present a complex social issue through simplified allegorical scenarios, and resolution would be achieved through the emotional and intellectual struggles of a team of well-trained experts at the peak of their careers. The first two films of the reboot reversed this pattern, telling unnecessarily complex stories built around a series of simple problems, resolved through the physical actions of sophomoric individuals who succeed through a mixture of individual exceptionalism and luck.

Part of your mind, right now, is interpreting detected patterns of light reflected from the objects around you, and the movement of air in and out of your body, and the balanced interaction between your muscles that is keeping you sitting upright. This information is very complex, but detecting and interpreting it remains on the periphery of our attention – that is – we don't focus on it at all under normal circumstances. You might be thinking of those processes now that I've brought them to your attention but, since they are not the focus of this little discussion, I will ask you to try to go back to ignoring for them for the time being.

Another part of your mind is worried right now. The worry might be expressing itself as gentle, cloying concern, or it might be foot-tapping nervousness, or even outright fear. It could also be taking the form of seething anger or nearly overwhelming frustration, but it is worry. As Spider Robinson has often written, "anger is always fear in disguise" [4]. In some schools of meditation this is referred to as the monkey brain – a primitive and distracting chatter of anxiety that keeps us from thinking clearly. Most of the time, this pervasive, unconscious worrying is much harder to ignore than balance or breathing or the objects in the background of your line of sight but – and this is important – most of the time we can ignore some of the fear and some of the time we can ignore most of the fear. Do you feel emotional now? Has your reading been interrupted by frustration or by thoughts of other things that have been bothering you? Can you ignore it and read on?

If we can get through the thick forest of sensory noise, and past the overly-emotional monkey that chatters incessantly there in the dark, we can reach the part of our mind that is capable of turning observed letters into unanticipated words and phrases, and of turning those phrases into meaningful ideas. Deep in that forest, rising above sensory trees and emotional monkeys, there stands an ivory tower. The part of your mind that is logical sits at a small window high in that tower with head in the clouds, and thinks rationally about the meager ration of sensory data it receives. That is the part of your mind that is reading this paper – if you've managed to maintain your focus.

And that is a key point.

McCoy: "I'm not talking about rationality."
Spock: "You might be wise to start."

The Galileo Seven

It is harder to use the rational part of your brain. It literally takes more energy to reflect clearly and calmly than it does to react with emotion. Reflection is also slower than reaction and both are slower and use more energy than purely reflexive behaviour – like the breathing and balance and sight that have already been mentioned.

The idea that we each have multiple minds in simultaneous use is not original with me [5]. Malcolm Gladwell believes that we have two processing systems that work at different speeds [6], as do Tversky and Kahneman [7]. Even the idea that we have three processing systems has been around for a long time, with key examples found in the legacies of Plato and Aristotle [8], and in the theories of Freud [9] and

of Jung [10]. The idea that the evolution of these separate types of mind can be related to the evolution of specific parts of the brain can be traced to nineteenth Century French anthropologist Broca who proposed specialization of brain regions [11]. His ideological descendant in the twentieth Century, Paul MacLean, is often credited with establishing the first model of the triune brain [12]. I have written about this myself [13], but I strongly recommend Carl Sagan's "The Dragons of Eden" [14] for any reader who wants a beautifully-written introduction to the idea – and to many other ideas, too.

Basically, brain structure reflects the evolutionary order in which these different types of interactive processes developed. Doesn't it make sense to think that the earliest systems, the ones that run constantly, would operate at a level of low energy consumption and with a low demand for attention? Imagine two ancestors we might have had a few tens of millions of years ago; one who had to think about each breath and each stage of digestion, and one who could use that same attentional processing power to look out for predators. We can easily imagine which one would be more likely to have lived to puberty, and so contributed to our gene pool. I propose that the order in which we developed our three different systems is responsible for the ranking of energy consumption and effort, in inverse relation to ease and speed.

Now, if you'll allow me, I'll express the idea again in different words. I hope that they are not too offensive. All of the genes we carry were filtered over millions of years of evolution, probably by the process of natural selection. In order to pass on any genes at all, the individual at each stage had to be able to survive. Survival can be seen at two levels. The more fundamental one is literally the biochemical processes of metabolic survival that we must be able to perform from birth: breathing, digesting, etc... As the ancient Greeks pointed out, even the plants can do that [8].

The next level of survival is the development and adaptation of learned behaviours in response to our environment. One who does not learn to do this well will not advance beyond infancy and the need for continual care, and so will not be likely to contribute to the genetic material of the next generation. As MacLean pointed out, primitive man had to be able to do this... though, as far as that goes, so did earlier primates, birds, lizards, and fish. Interestingly, the active nature of this learning – and the perceived genetic value of it – may well be responsible for mating rituals and displays of attractiveness among all of those species. This can be witnessed to hilarious effect in nature, and on YouTube. In my personal opinion, similar attempts by our own species tend to be even funnier.

From an evolutionary perspective, intellectual capacity is the least important of the processing systems because it doesn't get to come into play unless the other two have already been successful. I am certain that I am not the first *Star Trek* fan to wish that this were not the case, but that does not change the fact that being able to quote Harlan Ellison, David Gerrold, or Dorothy Fontana is simply not as important – from this perspective – as being able to walk attractively.

Spock: "I survive it because my intelligence wins out over both, makes them live together."

The Enemy Within

I want to stress that the relationships between speed, effort and energy consumption that is entrenched in this evolutionary order is not the most important aspect of my theory. In fact, that can already be derived from the earlier work cited above. The important part of my theory is totally contrary to almost all of the theories mentioned earlier. I believe that only Freud avoided the hubris that made the others assume that our thoughtful selves are in control. In fact, I theorize that the others all got the order of control completely backwards, and I propose that the evidence for this is found all around us. We do not exert conscious control over our unconscious – our unconscious is in constant control of the vast majority of our behaviours. It cedes control to our conscious and deliberate and rational thinking only under rare circumstances, and only for limited amounts of time. In the same way, our reflexes take precedence and control over our emotions.

We can force ourselves to pay conscious attention to things for a little while, but only some things, and only for a little while. Otherwise, it is either our reflexive system or our emotional, reactive system that responds to most of the conditions and situations we encounter. Professor Einstein wrote a short memorial for his friend Maria Sklodowska Curie, expressing his great admiration for her as a person and as a scientist. Here he praises her ability to maintain conscious focus:

> The greatest scientific deed of her life—proving the existence of radioactive elements and isolating them—owes its accomplishment not merely to bold intuition but to a devotion and tenacity in execution under the most extreme hardships imaginable, such as the history of experimental science has not often witnessed. [15]

Yes, he says that tenacity such as hers is rare, but he holds it up as the ideal. The notion that we must struggle to maintain conscious focus challenges our claim to be rational, thinking creatures. I've suggested elsewhere that we should change the name of our species to something a little more accurate – not "Homo sapiens sapiens" (the hominid who is so wise you have to say so twice), but "Homo sapiens reagens" (the hominid who has wisdom but reacts) [16].

Does the idea that humans don't think well amuse you? Does it upset you? Do you dismiss it out of hand? In either case you are reacting emotionally to an idea that is challenging your mental model of yourself. Why the emotion? Because that happens faster than the conscious thought, which is still being delayed because it is reading these words and trying to understand the argument. The emotional reaction started long before you read this last word.

Now, if you can accept this idea – at least as an idea to think about, not necessarily as one to believe – then I want to take it a little further. Now that you're thinking about the fact that we might not be very good at thinking, it's time to talk about how bad we are at sensing the world around us.

Kirk: "Sometimes a feeling is all we humans have to go on."
A Taste of Armageddon

With apologies to Bill Maher, it is a simple fact that we do not think about the world around us in real time. Our reflexive and reactive systems respond to the real

world in thousandths or hundredths of a second. Think about that. Did you notice how long it took you to think about that? Our rational system is a thousand times slower than our reflexes, and a hundred times slower than our first impulsive reaction!

The fact that we are not consciously aware of that suggests an idea that is measurably demonstrated but a little hard to believe. The rational and intellectual part of our thoughts is constantly trying to catch up with what we have already done, and has created an elaborate and ongoing illusion of deliberate action to justify most of our behaviour.

This is the practical side of Aristotle's "man in the cave" [17] and Descartes' "cogito ergo sum" [18]. To return to the illustrative model of the tower in the forest, the thinker in the ivory tower doesn't really know the difference between thoughts and dreams – and has no ability to tell what is accurately sensed or reported, and what is a mistake or a deliberate lie because he is too far removed from reality. What's missing from Aristotle and Descartes is an empirical understanding of just how far from reality we are. It is a measurable distance, and you have probably already measured it many times without realizing it. Let's take a look at one example.

Do you tie your own shoelaces? If so, stop reading for a moment, and try to imagine every single move you make with your fingers in order to turn the two ends of string into a sturdy knot. Please be precise and please don't skip over any steps. Once you have imagined each step, please continue at the next paragraph.

You're back? Now, if you did try that thought experiment, then there are two likely possibilities for how things just went. You either believe that you imagined each detailed step, or you realized that – off the top of your head – you don't know what they are. Most of you reading this are likely to believe that you have easily remembered each step... but have you? Did you start with your left hand or with your right? Which finger did you use to form the first loop? Finishing the task, which fingertip pinched against the tip of your thumb as you tightened the knot?

Still think you went through each step in detail? Maybe you did. To really find out, write out each step as a point form list, then give it to a friend and ask them to do exactly what is written. Hilarity will likely ensue.

You see, tying your laces involves repeating a pattern you have learned to do unthinkingly.

That kind of unthinking pattern of coordinated reflexes is happening all of the time. It's fundamental to how you walk and run, to how you manage to successfully reach for one particular thing or step around another. Unconscious pattern following is also fundamental to many types of social interactions – have you ever reached out to shake the hand of someone who couldn't, or answered an expected question instead of the unexpected one that was actually being asked?

That's an interesting part of your own behaviour that you may or may never before have tried to explicitly understand. It's a strange idea, that we react too slowly to the world around us. How we deal with it is even stranger.

We rely constantly on mental maps, impressions and beliefs about the world around us. We react quickly and emotionally to new information at speeds too fast for our rational minds. We are so immersed in our personally-generated virtual reality that we are slow to accept when it is inaccurate. What's more, we often refuse to

believe that we are wrong, or that we reacted incorrectly, sometimes building elaborate scaffolds of fantasy in an attempt to fortify an illusion that can no longer stand on its own.

A cynic might suggest that this is how superstition could become religion.

Spock: "Logic informed me that, under the circumstances, the only possible action would have to be one of desperation. Logical decision, logically arrived at."

Kirk: "Aha, ha ha. I see. You mean you reasoned that it was time for an emotional outburst."

The Galileo Seven

Many have suggested that our memories are often faulty [19]. Witnesses often have conflicting memories of events that they experienced together [20]. It may be that at least some of that conflict is actually due to the fact that each witness was working from a different mental model of what was going on. It could be that they are remembering correctly, but that they experienced different events.

Now that seems ridiculous, right? I recently had a conversation on this topic with a couple in a quiet restaurant in Lisbon. One of the two partners, an engineer by trade, resolutely refused to believe that his perception could be anything but correct because he was observing carefully and thinking deeply. The sad truth is that he was doing neither of those things. That is not meant to be a personal or professional insult, simply an observation of the fact that he is human.

He was convinced that his eyes were dutiful cameras, observing and recording everything around him, and that the microphones that serve as his ears were working just as well. Both systems were feeding constant streams of data into the central processing system that was humming away inside him, feeding a superbly rational cognition engine so that it could maintain a perfectly accurate understanding of the world around him.

Well, the simple truth is that his brain does not work that way and neither do his senses. No offense is intended. My brain and sense don't work that way either, and neither do yours.

I've mentioned that we live inside a self-generated, virtual reality. Please allow me to explain why these virtual realities are fictional.

Remember a few paragraphs back, when I made a point of saying how our senses work much faster than our cognition? Well, what I left out then was that they make a big sacrifice in order to function as quickly as possible. Our senses take small, fast samples and, as a result, they are terribly, terribly inaccurate.

Consider your eyes. You do not see in a constant stream of vision. Peter-Mark Roget, the polymath genius who invented the thesaurus, the sliderule, and more [21] published a brilliant and often mis-referenced paper in 1825 on the topic of the speed at which our eyes see, and the illusion of constant vision [22]. His observation led to the beginnings of animation. The practice of animation led in turn to an improved understanding of the degrees of change from one image to the next that would best maintain the illusion [23]. That led to the development of new technologies for making images that were similar enough, and for presenting them on a medium that could be displayed in rapid and consistent sequence. In this way, hand- made animation led to movies, films, videos, and animated GIFs [24].

Kirk: "No blah, blah, blah!"

Miri

So, our eyes don't see moving images, they just see a series of still images and interpret the right kind of change to mean motion. This means that our eyes are constantly scanning for changes that are recognizable as motion. In fact, if you look at someone's eyes while they're going on about some everyday task, you'll observe that they are in almost constant motion. The almost incessant tiny motions are called saccades, and they are pretty surprising the first time you notice them. What's more, they're also undetectable to the person doing them. How can that be? The answer is actually awesome. Before we get to it, let me ask you to do a little experiment with a mirror. This test was originally designed for people with two working eyes [24]. If you are fully- or partially-blind, and would like an example that is not vision-based, please write me directly. I would be happy to provide one based on hearing. If your vision and hearing are both limited, I would be happy to provide an example based on proprioception or touch. For now, let me continue with the simplest version, the one that will work for most readers.

Face a mirror and look at one of your eyes. After a moment, look at the other. Repeat three or four times. Now, repeat the process again but, as you do, pay attention to your eyes. Did you see them move? Try again and pay close attention. Can you feel them moving back and forth?

You will not see your eyes move. You cannot. When your eyes are moving your brain stops processing vision because there are too many changes to process quickly.

In fact, you are only seeing about 15% of the time you think you are [25]. More about that in a little while.

We think we are perceiving the world, but in truth we are perceiving small pieces of it and fitting them into a mental model.

This is why witnesses report conflicting experiences – they each actually saw different subsets of the real visual data, and they each actually fit them in to their own individually-fictitious mental models. They literally experienced different things at the same time and place. Give them time apart and the differences in their memories may broaden as they develop elaborate details supporting their individual understanding of the experience.

On the other hand, if you give them the chance to build these elaborate scaffoldings together, a sadly-predictable result is achieved. The individuals come to believe that they also witnessed fictional things invented by the others. This is even true about things that could only have been seen from the perspective of others. In this way, shared fictions are much less accurate than individual self-deception of the sort described above.

This is why scientific thinking requires independent observation and interpretation, even while it specifically requires that all observations and interpretations should be doubted and compared with the finished work of others.

We can only build dependable mental models if we are willing to challenge them with new data. To do this we elicit expert opinion from others – or as expert as possible – even though we might, on reflection, reject it.

This is why scientific thinking is so important, it teaches us to assume we are not understanding the world around us, and that we need additional people's opinions about the accuracy of what we think we have seen and how we have interpreted it, and the methods we have used for both.

Spock: "Has it occurred to you that there's a certain... inefficiency in constantly questioning me on things you've already made up your mind about?"

Kirk: "It gives me emotional security."

The Corbomite Maneuver

We want to trust our impressions and impulses, our quick reactive responses to the world around us. This leaves us with two choices. The first is to train ourselves so that our fast reactions are suitable to our situations. This is the case of practical experts in any field, from Judo players and skateboarders who have learned how to fall without getting hurt, to astronauts who have learned how to deal with emergencies even when deprived of sight or when in pain.

The second is to make false assumptions with great certainty, and count on our faith to pull us through – this is superstition and its younger sibling religion.

Earlier, I implied that Batman's foundational belief about criminals [26] could also be applied to humans in general; that we are "superstitious and cowardly". This is not a random insult, but an assessment of how we may think. We cling to our preconceptions against all evidence, literally unable to see the unexpected forest when we find that our field of view is crowded with an unanticipated number of trees. Our preconceptions and other cognitive biases weaken our individual ability to perceive the world around us. Telling fact from fantasy requires cooperation and formal, unintuitive thought. Scientific thinking is not the simple, intuitive work of a singular intellect, but a social activity. It is a method of altering the inherent iterative cycles of bias reinforcement and leaps of faith that we consider intuitive thinking, so that we explicitly define the weaknesses in our own ideas and count on others to help us find the flaws we've missed. A thousand years before René Descartes declared that our thoughts prove we exist [27], Augustine wrote "ergo sum si fallor" or "therefore I am because I err" [28].

Scientific thinking is about realizing that we each have these logical fallacies, and misperceptions, and inaccurate self-calibration, and so must try to work around those individual weaknesses and collaborate in order to improve the quality of our thinking.

> It is our responsibility as scientists, knowing the great progress and great value of a satisfactory philosophy of ignorance, the great progress that is the fruit of freedom of thought, to proclaim the value of this freedom, to teach how doubt is not to be feared but welcomed and discussed, and to demand this freedom as our duty to all coming generations. [29, p. 15]

In that way, scientific thinking is our gift to the future. The gift is not what we have learned, but that we have learned how to help each other learn. We have learned that knowledge advances in the freedom to doubt without shame. We have learned to see doubt as a sign of knowledge, and certainty as a sign of ignorance.

A scientific thinker separates their personal perception of their own self-worth from their faith in what they think they know. They do this by assuming they are wrong and asking others to check their work – not to prove the ideas right, but to try and prove them wrong. The knowledge that we are ignorant prepares us to receive new knowledge – not in a superficial way – but deeply.

This enables us to replace old mental models with new ones, again and again, avoiding the dogma of faith and certainty with the optimistic intent to keep learning. This is how the thinking of the many can be greater than the thinking of the one, so long as it is directed at modestly and methodically challenging information rather than attacking or supporting it blindly.

And that is the purpose of teamwork in *Star Trek*: Using many minds to improve ideas. In this way they show us how to seek out new facts and new information; to boldly disprove ideas that everyone has believed before.

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