Bayesian Thinking for Toddlers

Eric-Jan Wagenmakers
illustrations by Viktor Beekman

Bayesian Thinking for Toddlers

For Theo and Leanne

Once upon a time,
in a land far, far away,
Kate and Miruna were
debating who knows the
most about **dinosaurs**...

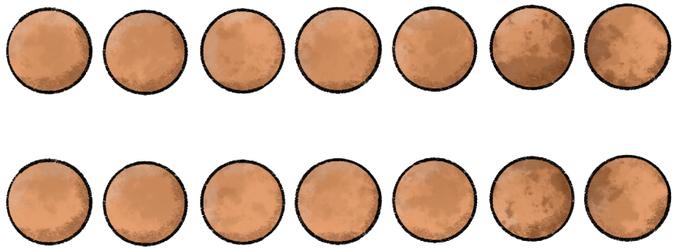
Kate

‘I can name each and every dinosaur!
And I can say “Huehuecanauhtlus”
really fast.’

Miruna

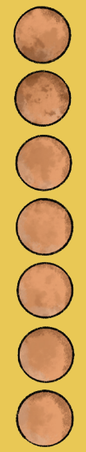
‘Look at my **crown**! Also,
I have watched a lot of television.
And my dad can buy me
as many dinosaurs as I like.’

Whoever knows the most about dinosaurs gets 14 homemade cookies from aunt Agatha.



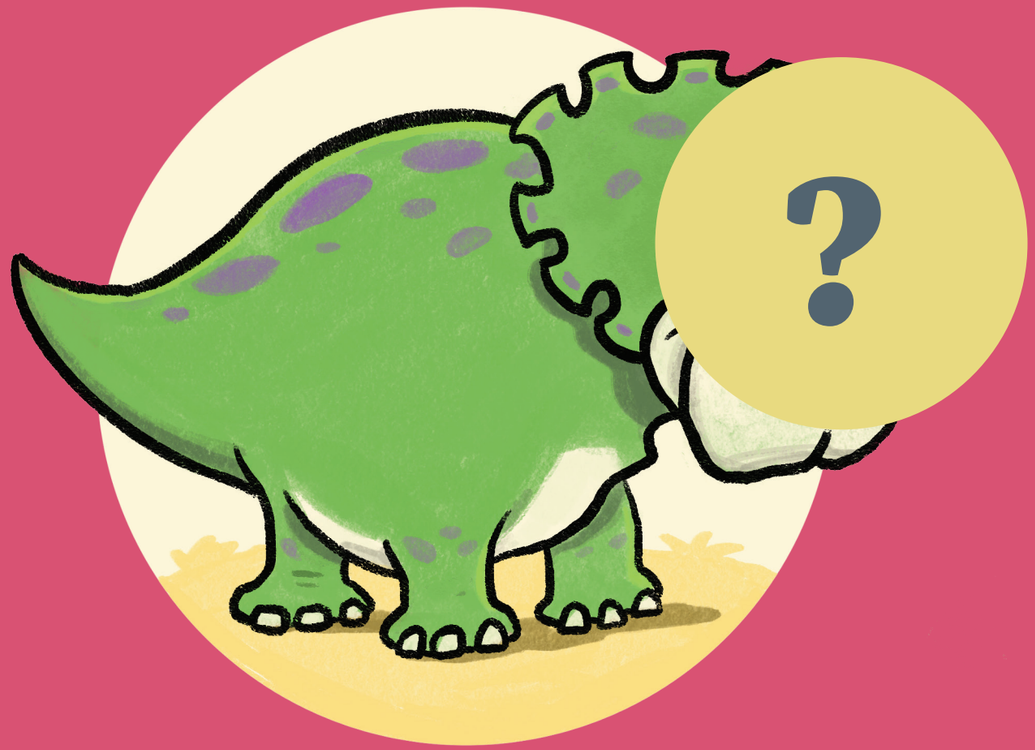
Aunt Agatha

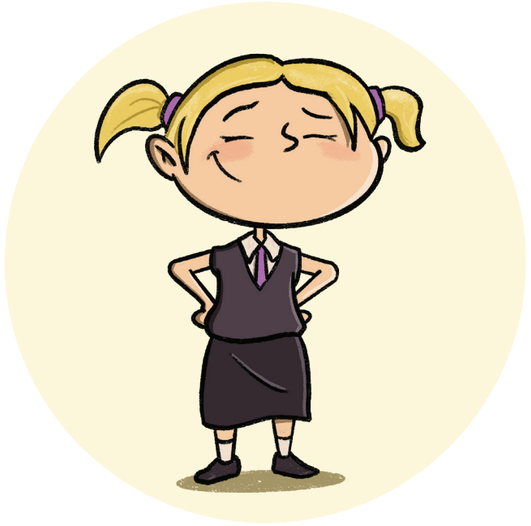
Aunt Agatha cannot tell
whether Kate or Miruna
knows the most about dinosaurs,
so she considers to divide the
cookies **evenly**.



But wait! Aunt Agatha has an idea. She will ask a **question** to help her determine who knows the most about dinosaurs.

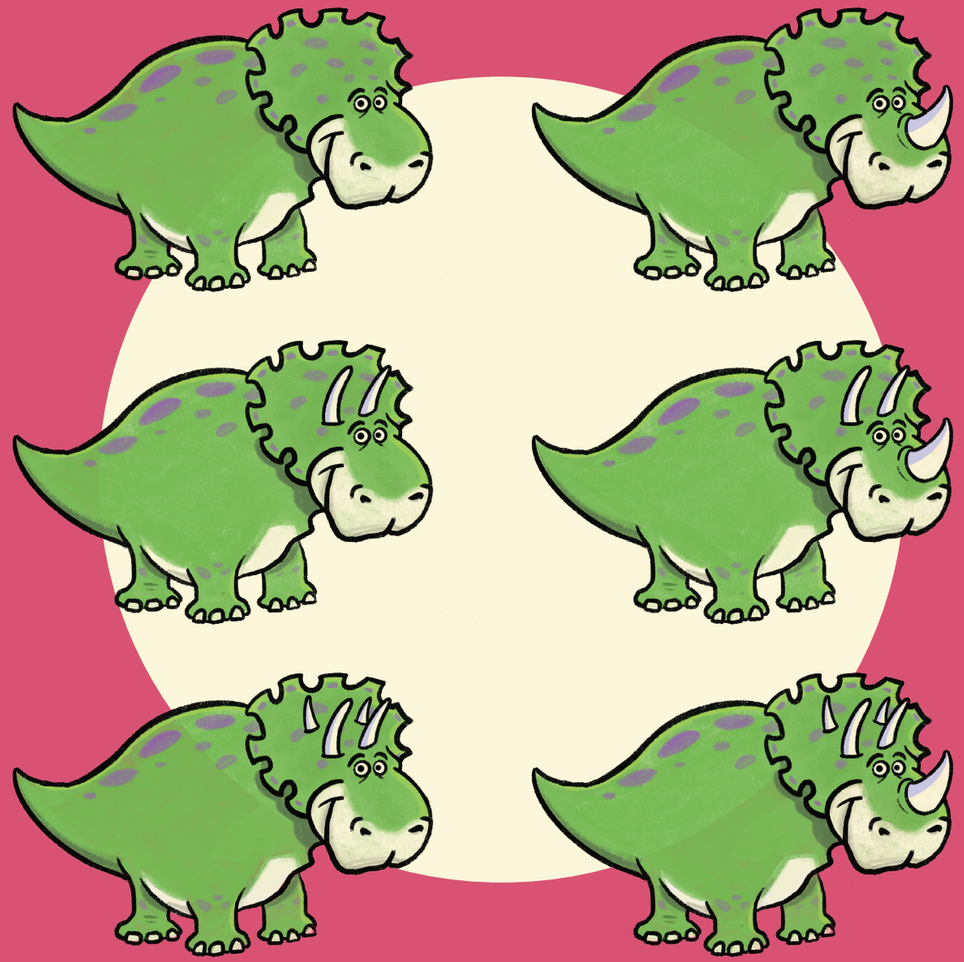
The question is:
‘How many **horns** does a
Triceratops have on its head?’





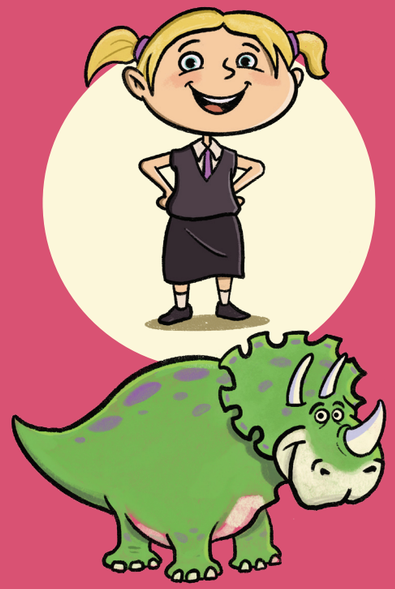
“**Three**! I am absolutely sure!”

"Oh, this is **difficult**! I am not sure.
It could be *none*, or *one*, or *two*,
or *three*, or *four*, or *five* – all of
these are equally likely to me!



The answer is *three*.
A Triceratops has three
horns on its head.

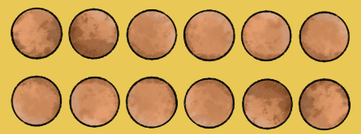
How well did Kate and Miruna predict the correct answer?



Completely correct!

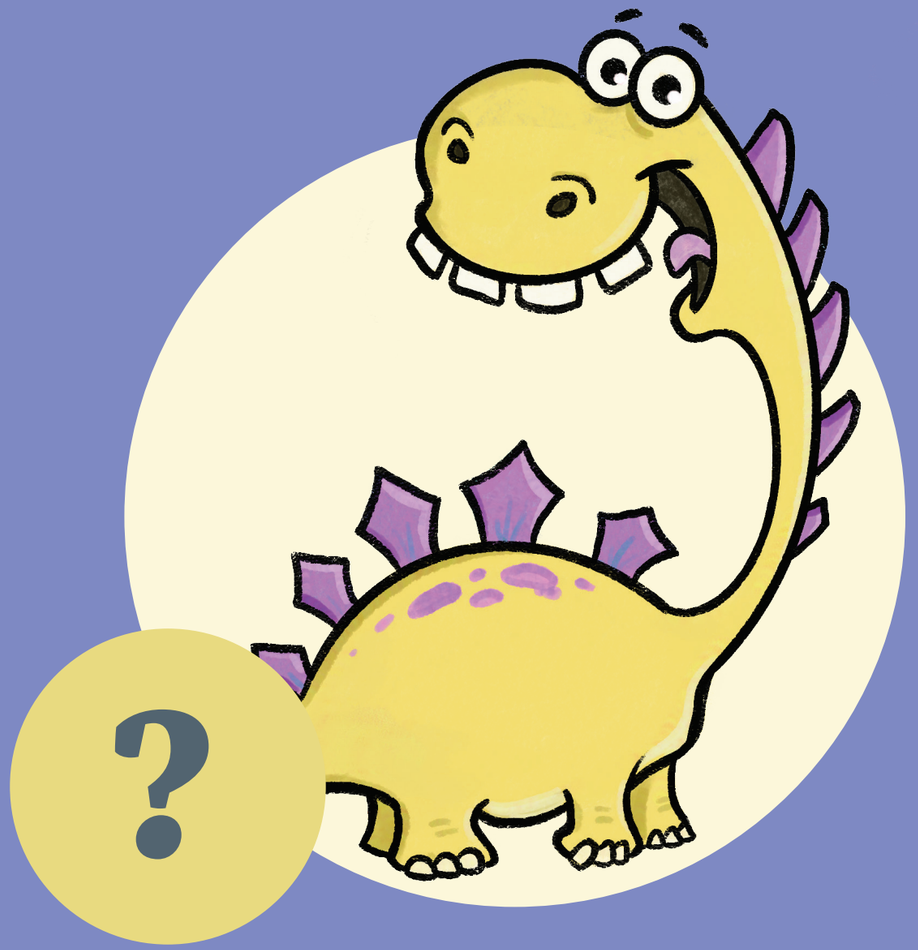
Correct for *one out of six* of her predictions!

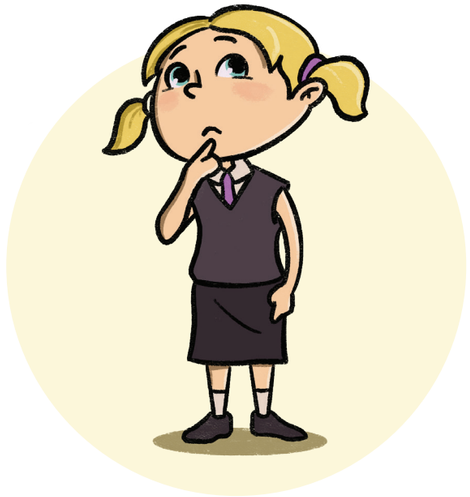
Kate **outpredicted** Miruna by a factor of **six.** So now aunt Agatha considers giving Kate six times as many cookies as Miruna.



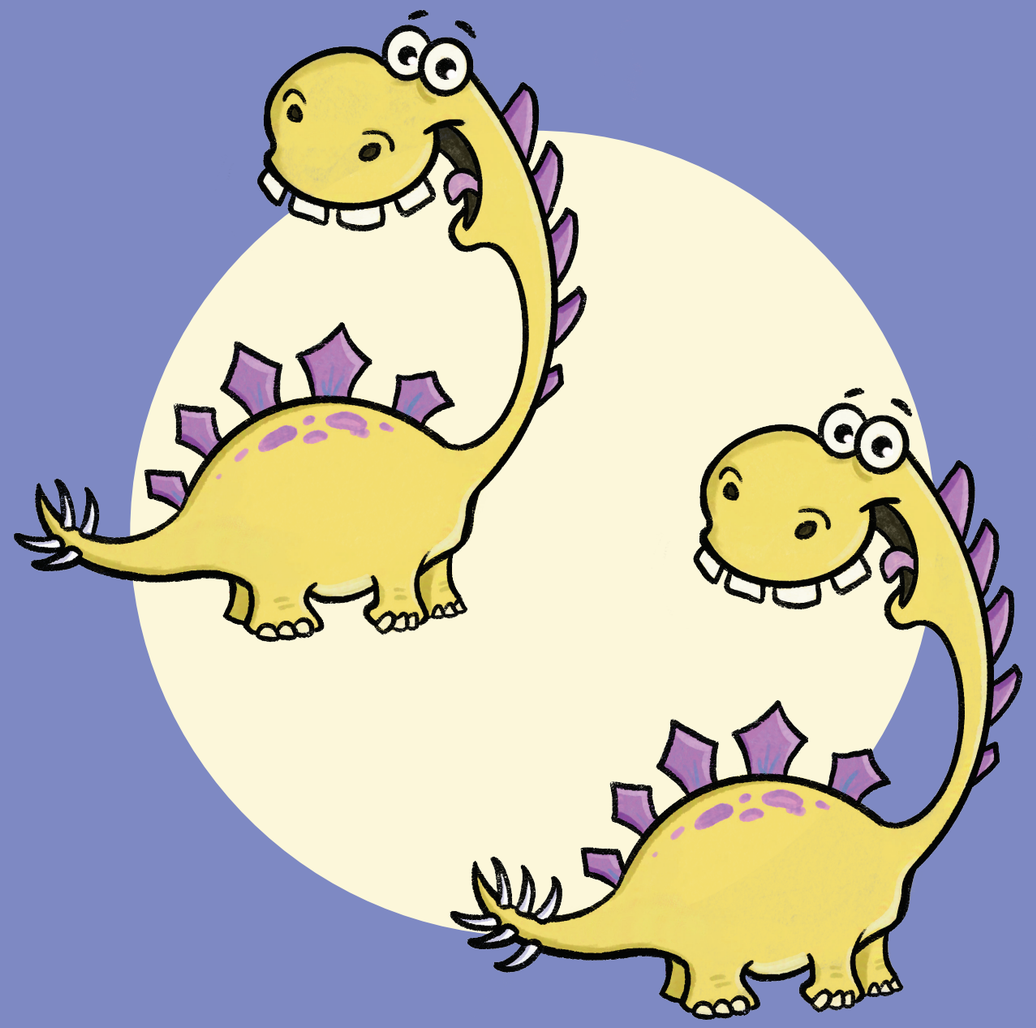
But wait! Aunt Agatha has another idea. She will ask a **second** question about dinosaurs! Are you ready?

The second question is:
'How many **spikes** does a Stegosaurus have on its tail?'

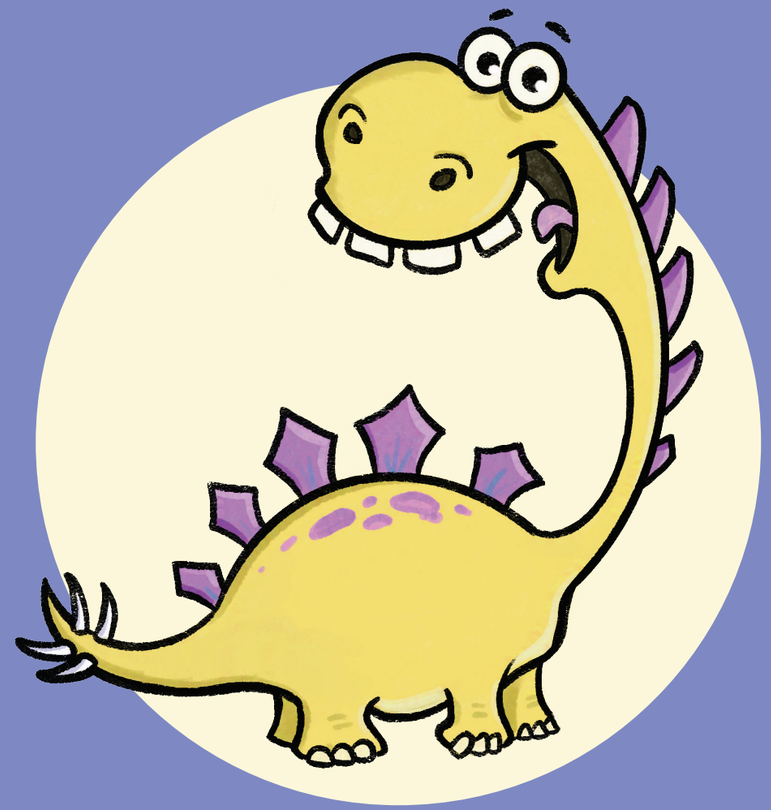




‘Hmmm. I am **not sure**.
Four or *six* spikes – both options
seem equally plausible to me.’



‘**Four!** No doubt about it!’



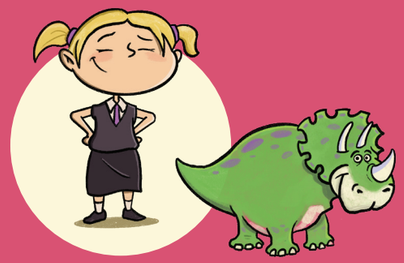
The answer is *four*.
A Stegosaurus has four spikes on its tail.

How well did Kate and Miruna predict the correct answer?

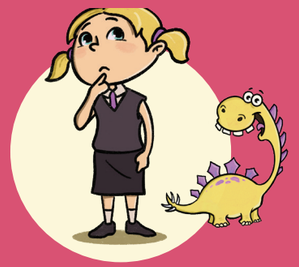
Correct for *one out of two* of her predictions!

Completely correct!

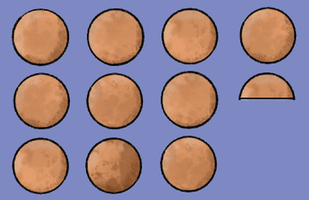
For the Triceratops question, Kate **outpredicted** Miruna by a factor of **six**.



For the Stegosaurus question, Miruna **outpredicted** Kate by a factor of **two**.



Overall then, Kate **outpredicted** Miruna by a factor of 6/2 = 3. Based on what she now knows, aunt Agatha feels that Kate should get *three* times as many cookies as Miruna.



Toddlers, what have we learned?

1 A Triceratops has *three* horns on its head.

2 A Stegosaurus has *four* spikes on its tail.

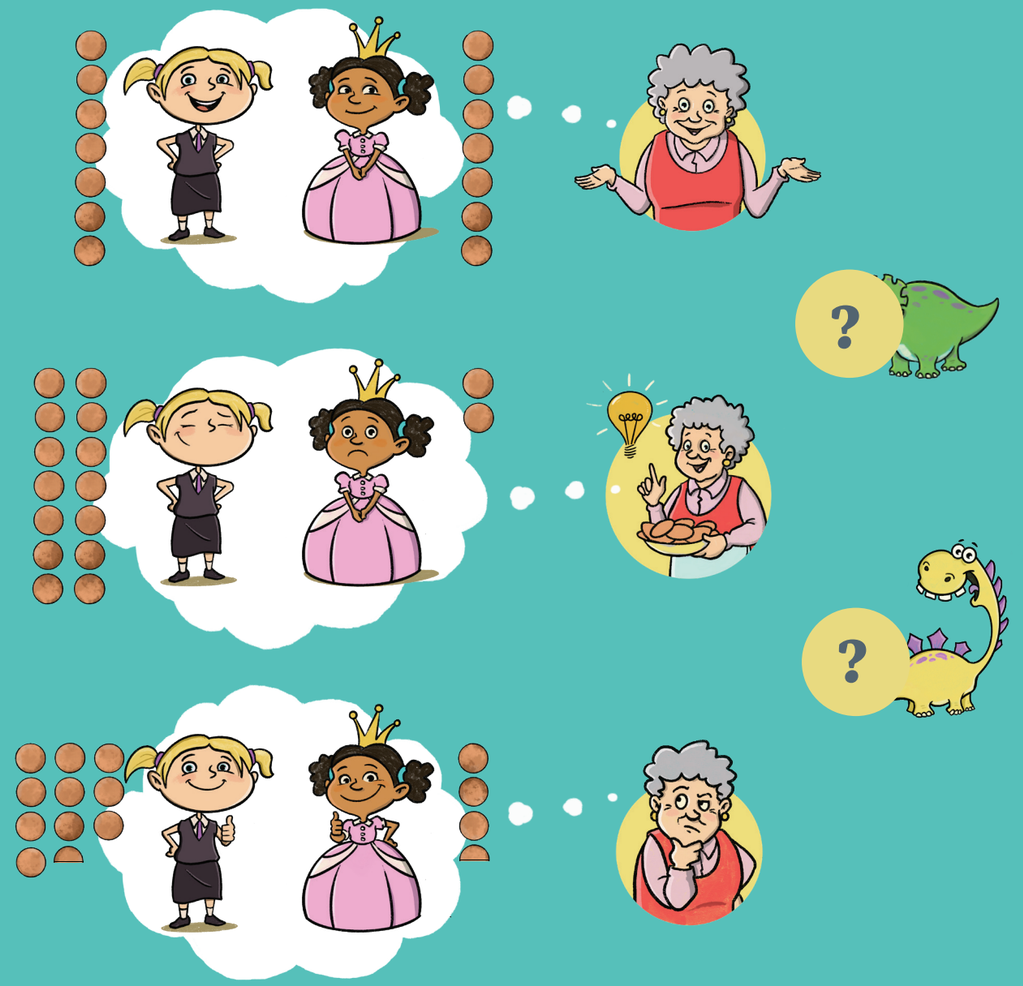
3 Cookies measure *confidence*

Kate **outpredicted** Miruna on the dinosaur test, and that's why aunt Agatha believes that Kate knows the most about dinosaurs – but aunt Agatha is *not completely sure*.

This is why Miruna still gets *some* cookies, even though she did *worse* on the test than Kate.

4 Over time, aunt Agatha *adjusted* her confidence that Kate knows the most about dinosaurs.

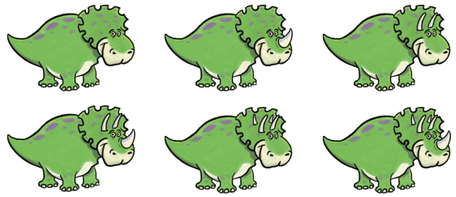
At first, aunt Agatha was *completely unsure*. After the Triceratops question, she felt that Kate *probably* knows the most. And then, after the Stegosaurus question, she started to have more *doubts* again.



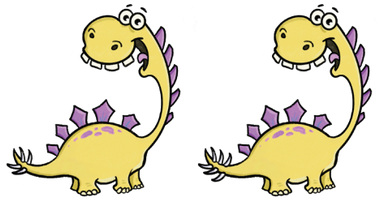
5 Kate did better than Miruna on the Triceratops question, but Miruna did better than Kate on the Stegosaurus question.

Each did better because knowing the answer *exactly* is more **impressive** than knowing it *vaguely*.

Knowing it *precisely*

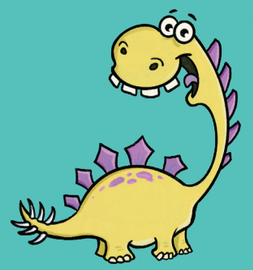


Knowing it *vaguely*



Toddlers, students, and researchers
can use JASP for more realistic
Bayesian analyses.
Download JASP for free at jasp-stats.org.

JASP



Eric-Jan Wagenmakers
illustrations by Viktor Beekman
Graphic design by Johan van der Woude
© JASP | 2020

Bayesian thinking is easy, and toddlers do it all the time. The fundamental principle is learning from experience: hypotheses that predict the data well receive a boost in plausibility, whereas hypotheses that predict the data poorly suffer a decline. For example, hypothesis A could state "At 6 am my parents will generally be asleep" and hypothesis B could state "At 6 am my parents will generally be awake". When a toddler then wakes up at 6 am and notices that both parents are still sound asleep, this observation increases the plausibility of hypothesis A and decreases that of hypothesis B. Easy!

Knowledgeable readers will discover that the dinosaur cover story hints at concepts such as Ockham's razor, coherent knowledge updating, and probability as degree of reasonable belief. Statisticians may recognize Phil Dawid's prequential principle in action.
Toddlers may just want to look at the dinosaurs.

Eric-Jan Wagenmakers is professor at the Psychological Methods Unit of the University of Amsterdam. He is the founder of JASP (jasp-stats.org), a free and user-friendly program for both Bayesian and non-Bayesian statistical analyses.

Viktor Beekman is a creative designer and illustrator from Hilversum.
See more of his work on Instagram: @viktordepictor