Cumulative improvements in iterated problem solving

Pierce Edmiston, *Maxime Derex, Gary Lupyan*

The cultural inheritance of problem solving knowledge

Why are humans effective problem solvers?

- We evolved specialized intelligences (Pinker, 2010).
- We developed systems of cultural inheritance (Boyd et al., 2011).

It seems relatively uncontroverial to say that humans are effective problem solvers, but it is worth considering what the evidence actually is, that we are good at problem solving. One way to think about it, from an evolutionary perspective, is that our species, and no other, has been able to solve the problems necessary for survival in nearly every terrestrial environment on the planet. Here I'm showing a few examples: human settlements in the Moroccan desert, the Brazilian rainforest, and the Canadian arctic. No other single species is able to do this. So what are the explanations for why humans are so good at solving different kinds of problems?

One answer to this question is that we evolved specialized intelligences. On this view, we are effective problem solvers because our brains evolved so that individuals could be smart and solve different kinds of problems on their own.

An alternative view is that we owe our success in problem solving in large part to our systems of cultural inheritance. On this view, it's not our ability to solve problems as individuals that is all that impressive. Instead, it's our ability to copy other people and benefit from their work that makes us adaptive problem solvers. Humans may be smart, but cultures are smarter.

Lost European explorer experiments[1]

> "Starvation on nardoo is by no means unpleasant, but for the weakness one feels, and the utter inability to move oneself, for as the appetite is concerned, it gives me the greatest satisfaction."

A favorite source of evidence for why cultures are more adaptive than individuals comes from what Rob Boyd has termed the Lost European explorer experiments. This is where a group of intelligent and well-equipped

[1](Boyd, 2018; Boyd, Richerson, & Henrich, 2011; Henrich, 2015)

Figure 1: Human settlements in the Moroccan desert, the Brazilian rainforest, and the Canadian arctic.


Figure 2: The nardoo acquatic fern, native to Australia.

adventurers somehow gets stranded in a foreign land, and the test is whether they can survive off the land long enough to make it back home. The irony of these experiments is that the explorers often die right alongside indigenous populations who have somehow figured out how to thrive in the same environment.

An example of this is the Burke and Wills expedition across Australia. As they ventured across inland Australia they were running out of supplies, but they ran into a group of Aborigines that was surviving off the land just fine. They saw that these Aborigines survived largely by eating an acquatic fern called nardoo, pictured here. The Aborigines prepared this plant by mashing it into a paste and forming it into little cakes. But all the explorers saw was that the Aborigines were eating a lot of nardoo, and so they assumed it wasn't harmful. It turns out that the food preparation process removed toxins from the nardoo, and when eaten unprepared, it caused a form of thamine deficiency that ultimately lead to their deaths.

Here is a passage from Wills diary shortly before he died, describing how odd it was to die of starvation with a full belly.

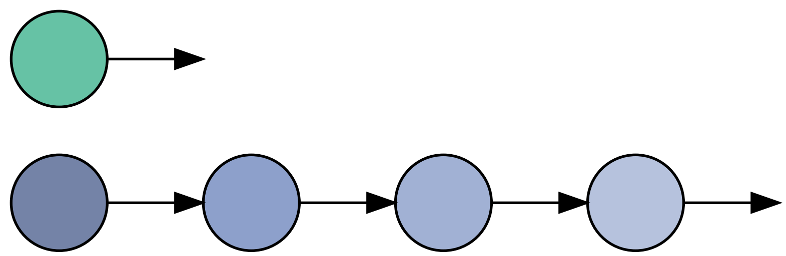
> Starvation on nardoo is by no means unpleasant, but for the weakness one feels, and the utter inability to move oneself, for as the appetite is concerned, it gives me the greatest satisfaction.

The Lost European explorer experiments demonstrate that in some cases cultures seem to be better at solving problems than any individual plopped down in the same environmental conditions.

The adaptiveness of cultural inheritance[2]

Cultural inheritance is adaptive because **even smart people die.**
Cultural inheritance enables problem solving to extend far longer than any lifetime.
How effectively does problem solving accumulate over generations?

[2](Boyd & Richerson, 1985; Richerson & Boyd, 2005)



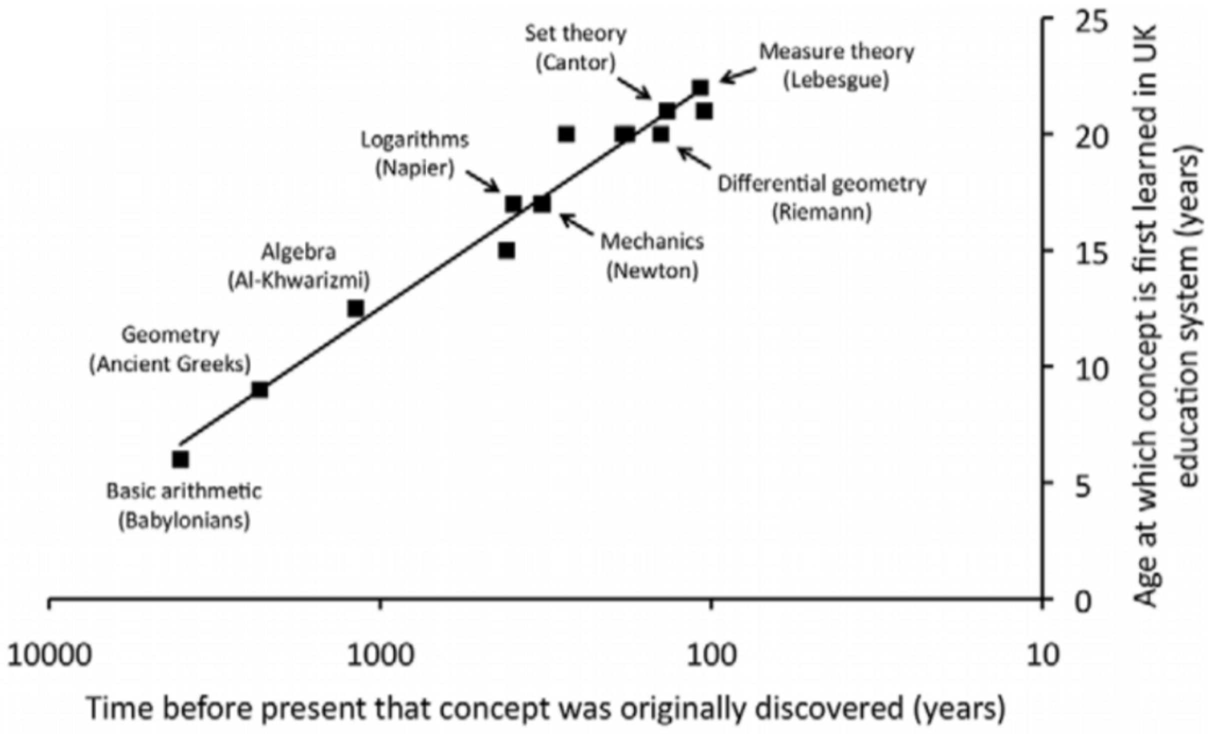
Why is cultural inheritance adaptive? Why is it more beneficial to be able to copy someone else than it is to be able to solve problems as individuals?

One of the basic arguments given for why cultural inheritance is adaptive is that even smart people die. If you cannot copy, you can only accomplish so much on your own in a single lifetime, no matter how smart you are. If you can copy, you can instead spend your life improving what other people invented. What this means is that problem solving can extend far longer than any single lifetime. Eventually, cultures can solve problems that individuals cannot.

This argument makes sense to me, but it also assumes something that I think should not be ignored, and that is that, on this view, problem solving is relatively unaffected by cultural inheritance. A person in generation 1 has the same problem solving capacity as a person in generation 4. All cultural inheritance gives you is a head start or shortcut to individual learning.

The question I am interested in is this: How effectively does problem solving accumulate over generations?

Increasing acquisition costs[3]



One reason why cultural inheritance may not accumulate effectively over generations is related to the idea of increasing acquisition costs. This is the idea that before you can solve any new problems, first you have to re-learn what everyone before you has already done. As the amount you need to re-learn increases, you have less time to discover new things.

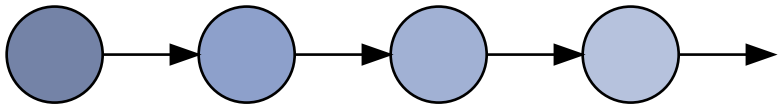
Here's a figure from a paper by Alex Mesoudi showing the relationship between when a mathematical concept was originally discovered and the age at which that concept is conventionally learned. Note that the x-axis is logorithmic. The basic idea is that masters students in mathematics, in their early 20s, are still learning ideas that may be over 100 years old, in part because they need to learn the foundations of mathematics before they can learn the most recent innovations.

Whether this sort of historical recapitulation is necessary for educational practice is debatable, but what I want you to take away from this example is that there are two things going on with cultural inheritance: the first is learning what has been done previously, and the second is improving or extending previous work.

So we can ask which is more likely to constrain cultural accumulation: is it the increasing cost of acquiring previous knowledge, or is it the inability to discover new things?

[3](Fig. 2A, Mesoudi, 2011)

How does problem solving accumulate?



Experimental models of cumulative culture:

- building paper airplanes
- knapping stone tools
- constructing baskets
- solving puzzles on a computer

The purpose of my research was to better understand this question: how much of a head start can be given to future generations?

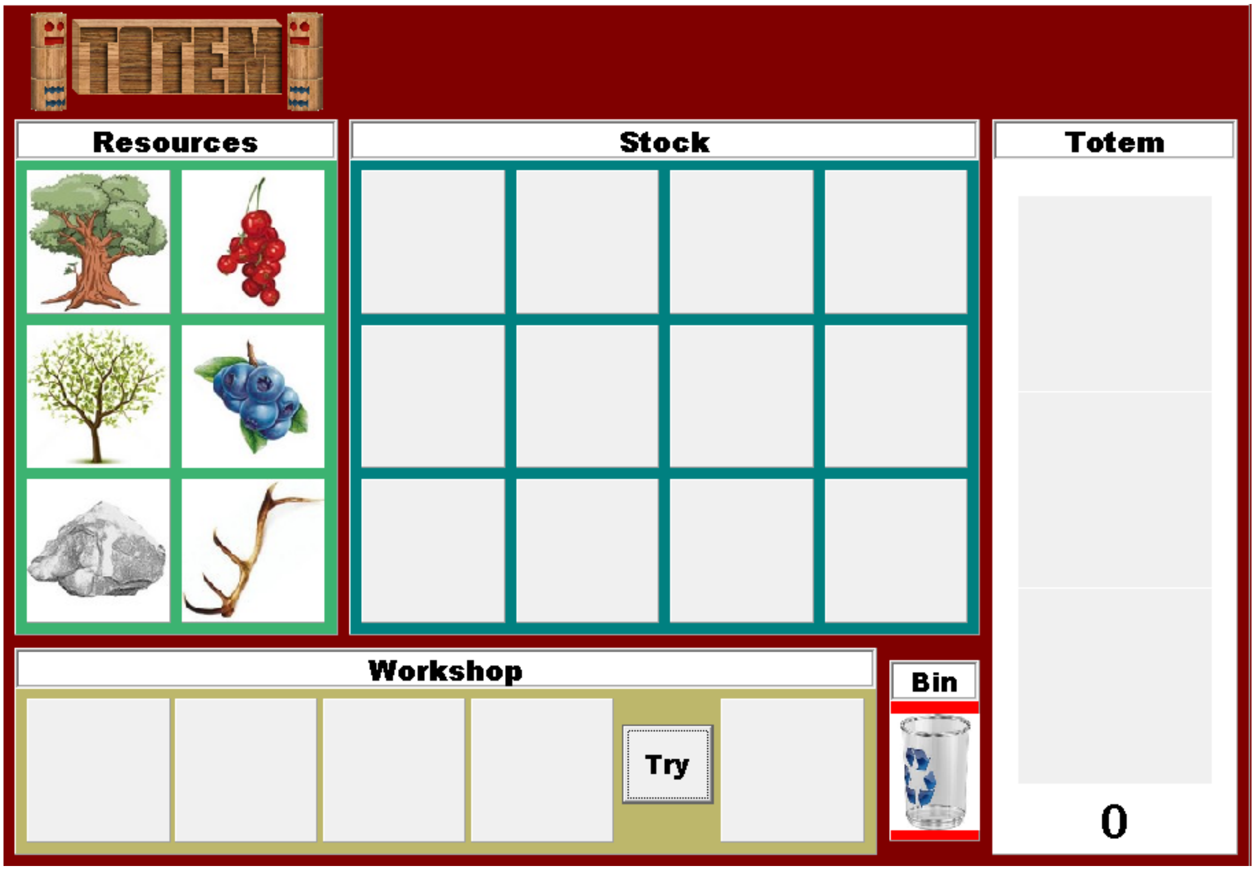
The idea that each new generation is able to build upon the accomplishments of the previous one is generally known as "cumulative culture". Cumulative culture seems obvious looking around today. Technologies like cars, computers, and spaceships are only possible because of generations of accumulated innovations. But it's only recently that we have really tried to establish good experimental models of cumulative culture. While we all may agree that cumulative culture occurs at the longest timescales, it's still an open question whether we learn anything about human problem solving by studying cumulative culture at the shortest timescales.

Previous experiments investigating cumulative culture have used a number of different experimental models. For example, if you watch someone build a paper airplane and fly it, and then you attempt the same task, chances are you can build a paper airplane that will fly a bit further than your ancestor, at least through a handful of generations.

This sort of accumulation depends heavily on the task, of course. People have also done experiments where participants learn how to knap stone tools, which is a much more complicated task than building a paper airplane. For these experiments, participants don't improve upon the stone tool design, but we are able to better understand how reliably skills are passed on to the next generation.

Most recently, experimental models of cumulative culture have started to look more like cognitive psychology experiments in that they have people solve puzzles on a computer where aspects of the problem solving task can be more tightly controlled than in an experiment involving the creation of physical artifacts.

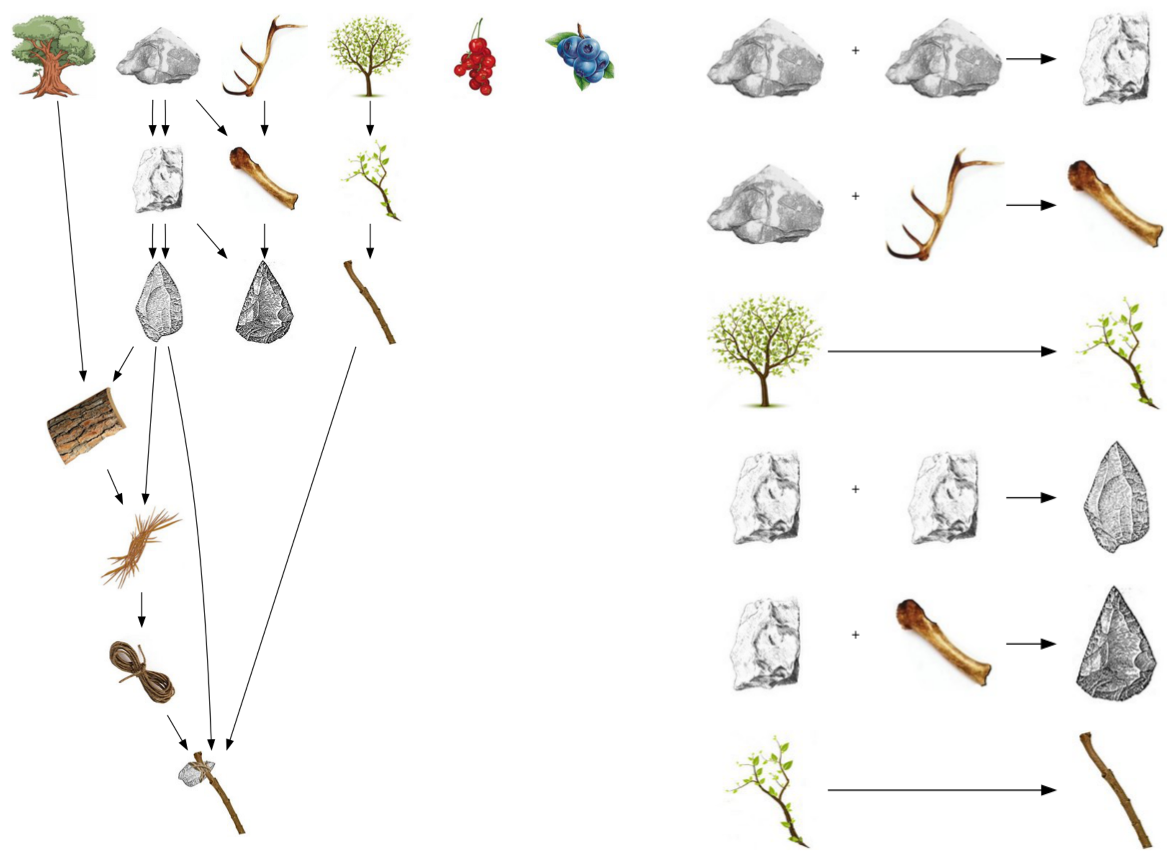
The Totem Game (Derex & Boyd, 2015)



An example of this is the Totem game. In the Totem game, participants attempt to build a totem pole first by combining these resources to make tools, and using those tools to create other tools, and so on and so on, until they can chop down a tree, and carve and paint a totem pole.

In this game, most of the combinations participants try do not yield new tools, and so the test is how effectively participants can search the space of possible combinations without making the same incorrect guesses over and over again.

Solution landscape



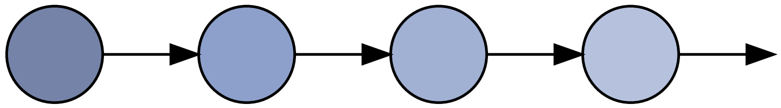
What makes this game interesting is that as tools are accumulated, the space of possible combinations increases exponentially.

Here I'm showing the first 6 generations of tools, leading to the first axe, which is required to make the simplest kind of totem pole. The landscape goes on beyond this point, but in reality, in just 25 minutes, participants have a hard time getting even this far.

On the right, I'm showing the recipes for the tools: the combinations of items participants had to make in order to discover the tool. So first they had to combine two stones to make a more refined rock, and a stone with an antler to make a club, and so one. Some items could be refined all by themselves, so you could break a branch off a tree, and refine a branch into a stick by trying these items individually. Most tools involved the combination of between 2 and 3 items.

Presumably, with more items, the game gets harder and harder, so we can ask how individuals who inherit a bunch of items from an ancestor are able to exceed them. Are they able to overcome the acquisition cost of recreating the previous tools?

Methods



- 42 complete chains (N=168 participants).
- Each participant played the Totem game for 25 minutes.
- Participants in Gen. 2-4 inherited **recipes** from their ancestor.

Research questions

1. How likely are future generations to exceed their ancestors?
2. Does inheritance have an impact on new tool discovery?

In this experiment, we recruited 168 participants and assigned them to 42 complete four-generation chains. Each participant played the Totem game for 25 minutes. Participants in Generation 2 through 4 started off with the **recipes** for all tools discovered by their ancestor. So they could see which tools their ancestors had discovered, and they could click on them to see the combinations that created them.

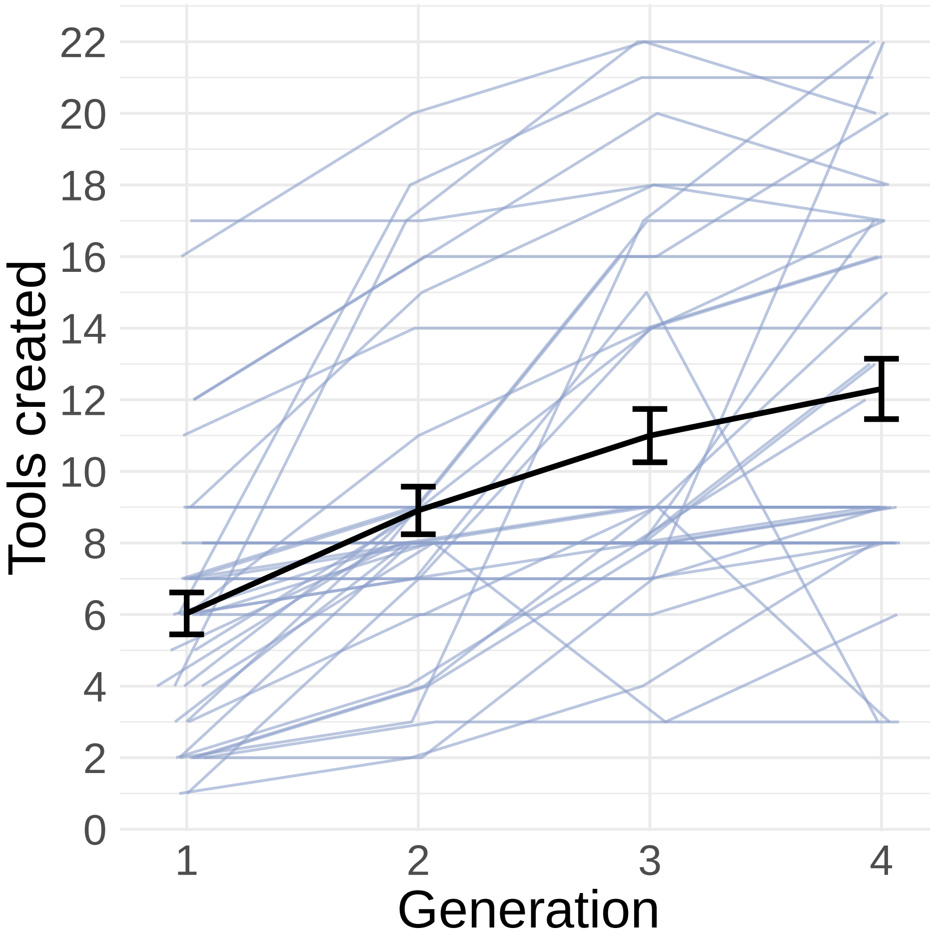
This is important because by inheriting the recipes, and not the tools, the first thing each participant had to do was recreate the tools discovered by their ancestor before they could attempt any new tools.

My main research question was how learning from someone else's successes was different than discovering the same tools individually. I asked this in two ways.

First, I asked how likely future generations are to exceed their ancestors. After recreating the previous tools, can they continue on and discover new ones, or do they just become stuck because they have too many items.

Second, I asked whether inheriting has any impact on new tool discovery, so after recreating tools discovered by someone else, is your rate of new tool discovery affected?

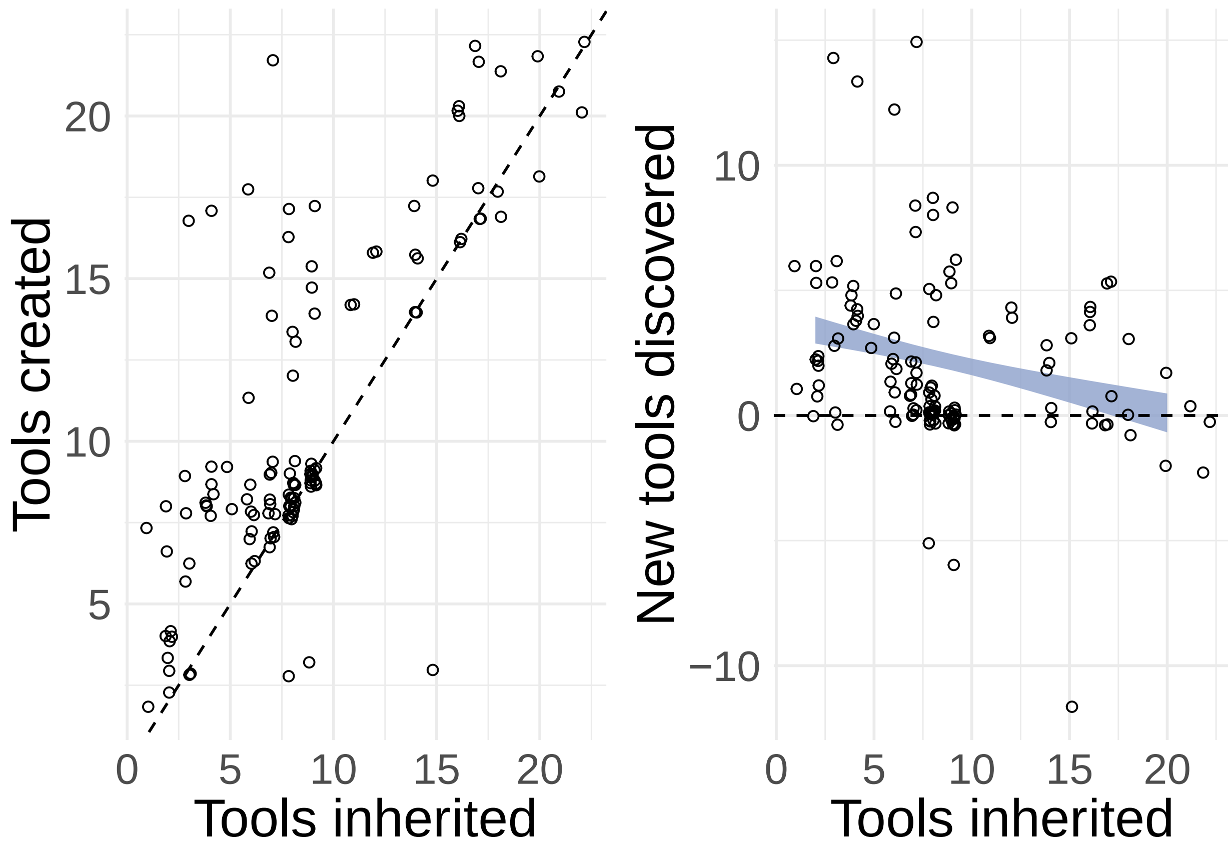
Tools by generation



First I'll just show you the results by generation. So here each thin line is a chain, and you can see that each generation tended to discover more tools in 25 minutes than their ancestor.

You can see that this is a quadratic fit, indicating that later generations had a harder time exceeding their ancestors than earlier generations.

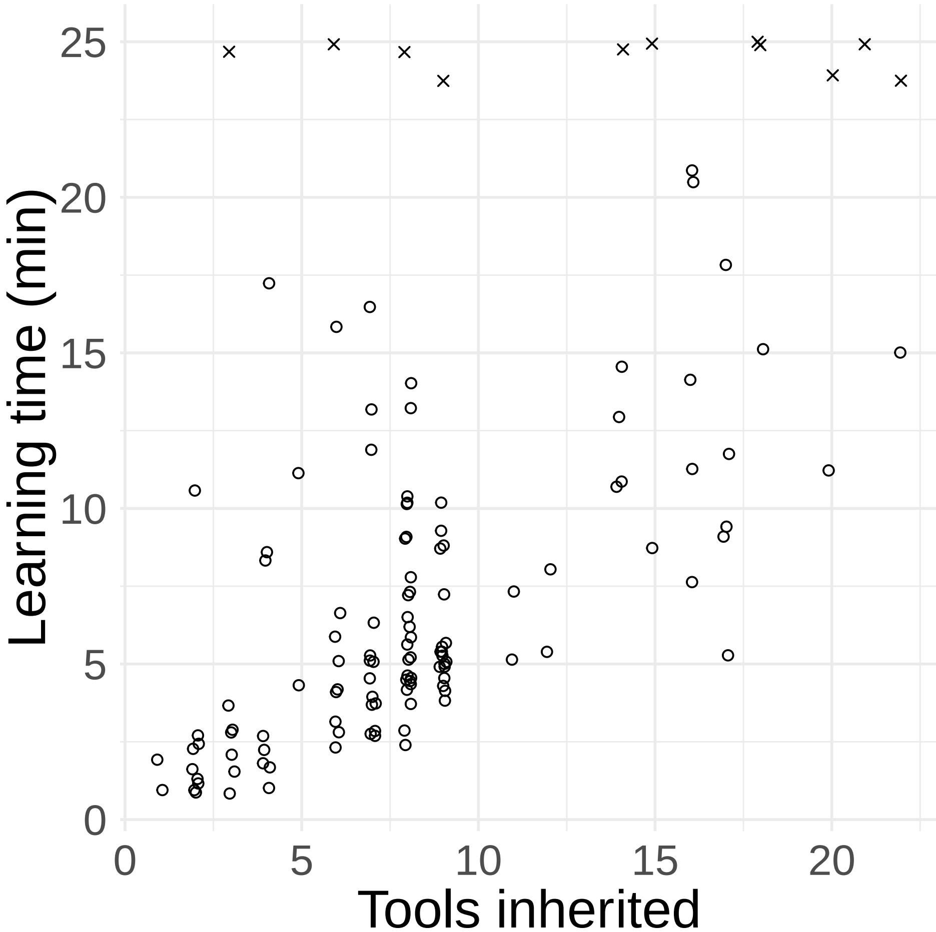
Tools by inheritance size



Next I'm going to show you the same data, but this time based on the number of inherited items, rather than by generation. The reason is that there is no difference between a second generation participant inheriting 6 tools and a fourth generation participant inheriting the same 6 tools.

On the left you can see the relationship between number of items inherited and number to tools discovered. The dotted line is a reference line with a slope of 1, so people who fall along that line recreated the tools they inherited but were unable to create any new tools. As you can see, most of the points are above the line, but to get a better sense of the relationship, look on the right, where the same reference line is now horizontal, and you can see the negative slope best fit line, indicating that as participants inherited more tools, they had a harder time exceeding those tools.

Learning times

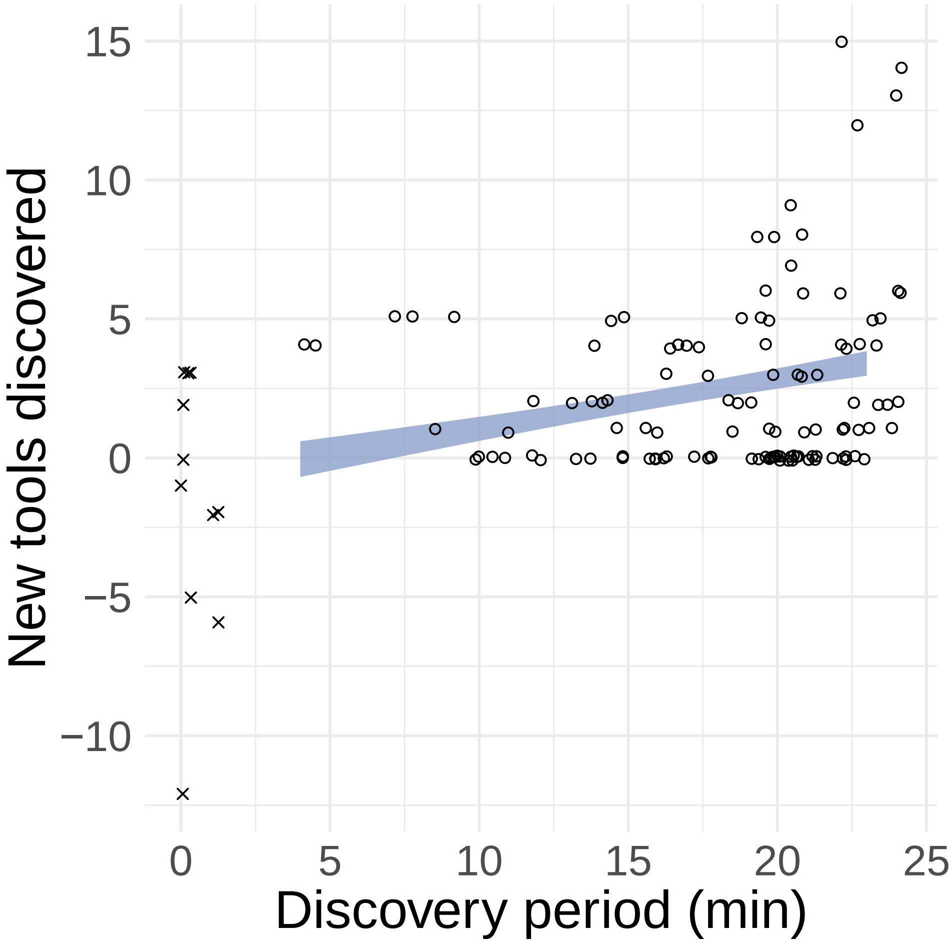


Now I want to dig in to what explains why inheriting more tools seemed to decrease future problem solving ability.

The first way to do this is to take into account how much time in the 25 minute session participants spent recreating existing tools as opposed to discovering new ones.

Here I'm showing you the relationship between the size of the inheritance, and the amount of time spent recreating the inherited tools, and you can see the expected positive relationship, indicating that more tools took proportionally longer to recreate.

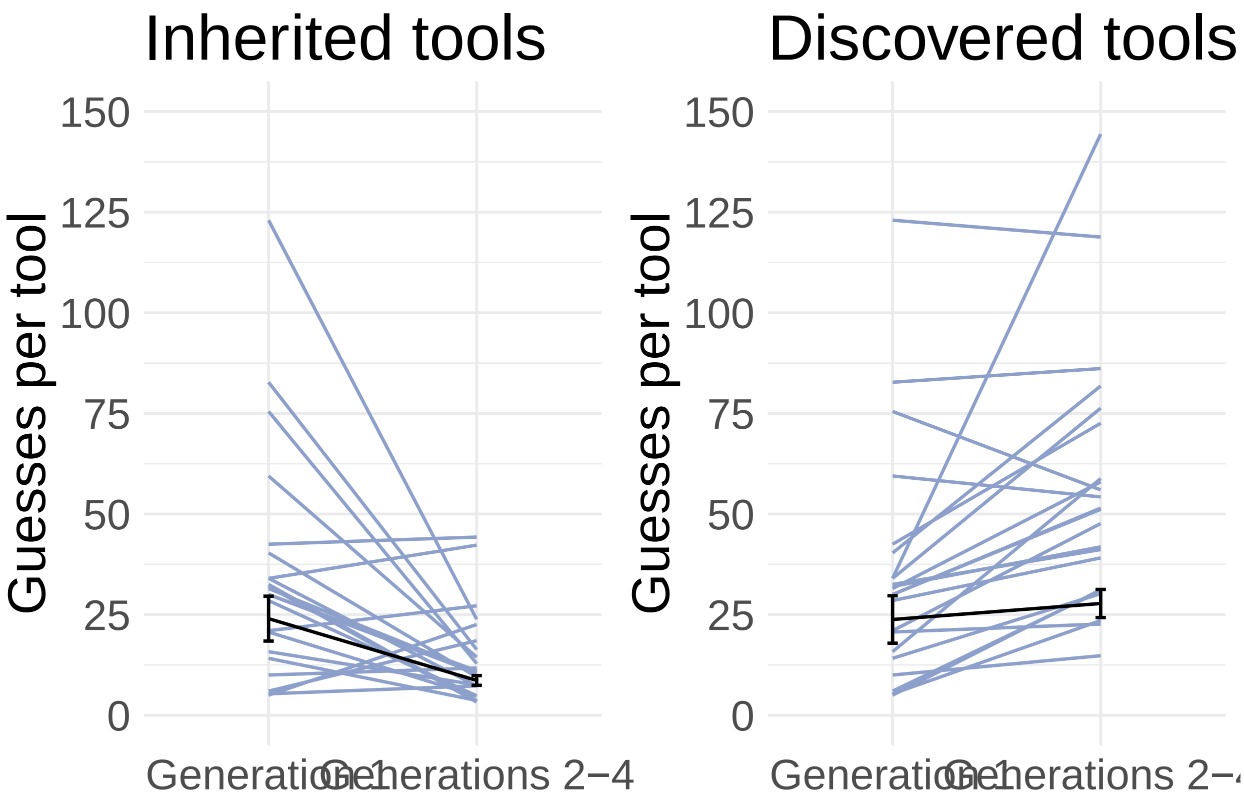
Discovery rates



Now we can ask how effectively participants were able to discover new tools taking into account how much time it took them to recreate the old tools.

Here I'm showing that people who had more time to discover new tools tended to discover more tools, but what's interesting is that the slope of this line does not vary based on the number of tools that were inherited. That suggests that even participants who inherited a bunch of tools were not any slower at discovering new tools, they just had less time to do so.

Guesses per tool



The last analysis I'll show breaks things down further by the number of guesses made for each tool. In the previous analyses, I treated all tools the same, but here I'm saying, for each tool, from the moment at which the tool was available to be discovered, how many guesses did it take to discover it.

Here I've split things up based on whether the tool was inherited from an ancestor, or it had to be discovered new. So on the left, you can see the benefit of inheriting. Each line is a tool, and participants who inherited the recipes for those tools were able to recreate those tools very quickly.

But the interesting test is on the right. Here I'm asking whether learning from someone else's solutions gave you any sort of insight into the discovery of new tools as opposed to discovering all tools on your own. The lack of an effect here is interesting because it indicates that inheriting from an ancestor does not have an impact on future problem solving.

Summary

1. How likely were participants able to exceed their ancestors?

- Participants were able to solve more problems in 25 minutes than their ancestors.

2. Does inheritance have an impact on new tool discovery?

- No effect on the rate of new tool discovery.
- No effect on the number of guesses required for new tools.

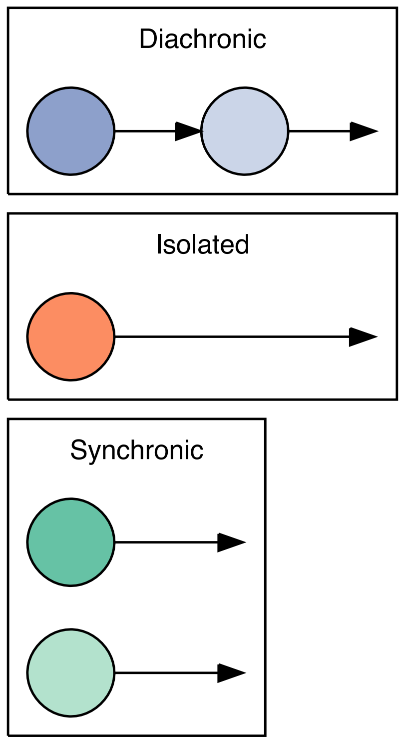
To wrap things up, I found that participants were able to solve more problems in 25 minutes than their ancestors. This type of iterated problem solving is known to be an important factor in human evolution, and here we've added to our understanding of how problem solving knowledge accumulates over generations.

To me the more interesting question is whether we can detect an impact of inheritance on new tool discovery. However, we didn't find any effects on the rate of new tool discovery, and neither did we find an effect on the number of guesses required for new tools.

Why isn't this the complete story?

How does iterated problem solving compare to alternative strategies?

- Is it better to pass on to the next generation or continue on individually?
- Is it better to work in sequence or in parallel?



This work is just starting, I want to briefly mention some of the other questions we have using this paradigm. The main limitation to me is that we might get more understanding about iterated problem solving if we compare an iterated strategy to alternative ways of solving the same set of problems. That allows us to answer questions like: Is it better to pass on to the next generation or continue on individually? and Is it better to work in sequence or in parallel?

I have some of these results, but didn't have time to talk about them here, so if you are interested in them, please feel free to ask me about them after.

Cumulative improvements in iterated problem solving

Pierce Edmiston, Max Derex, Gary Lupyan
pedmiston@wisc.edu
osf.io/vf2wk
github.com/pedmiston/iterated-problem-solving

References

Boyd, R. (2018). *A Different Kind of Animal*. Princeton, NJ: Princeton University Press.

Boyd, R., & Richerson, P. J. (1985). *Culture and the evolutionary process*. University of Chicago Press.

Boyd, R., Richerson, P. J., & Henrich, J. (2011). The cultural niche: Why social learning is essential for human adaptation. In *Proceedings of the national academy of sciences of the united states of america* (pp. 10918–10925). University of California, Los Angeles, Los Angeles, United States.

Derex, M., & Boyd, R. (2015). The foundations of the human cultural niche. *Nature Communications*, *6*(1), 1–7.

Henrich, J. (2015). *The secret of our success: how culture is driving human evolution, domesticating our species, and making us smarter*. Princeton University Press.

Mesoudi, A. (2011). Variable cultural acquisition costs constrain cumulative cultural evolution. *PloS One*, *6*(3), e18239.

Pinker, S. (2010). The cognitive niche: Coevolution of intelligence, sociality, and language. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(SUPPL. 2), 8993–8999.

Richerson, P. J., & Boyd, R. (2005). *Not by genes alone: How culture transformed human evolution*. University of Chicago Press.