TuneTrace: a question of chance or a chance for a question?

The tunes that TuneTrace plays are all produced by following a set of instructions. The instructions tell it how to move the lights around the drawing. Those instructions are contained in every TuneTrace app before it's even seen a drawing.

All computers contain a set of "low level" instructions like these. In fact, if you imagine the lights are 1s (and their absence are 0s) then the lowest level instructions in a computer are very like TuneTrace's; they do nothing but move 1s and 0s around a very big circuit.

TuneTrace's instructions haven't got anything to do until it sees a drawing. The instructions are applied to the drawing. The drawing is like a computer program. It's something you write that can be interpreted as a sequence of instructions.

Instructions can lead to random or deterministic results. A random result is like flipping a coin: it's impossible to know the result before you do it. Deterministic means that the result is predetermined before the action happens, like if you just turned the coin over in your hand.

If all of TuneTrace's instructions are deterministic then you could look at a drawing and predict exactly what its tune would be. It's just that, for an even slightly complicated drawing, it would take you lot of time to follow the instructions. Following instructions is what computers can do *fast*.

If any of TuneTrace's instructions are random then it would be impossible, even for a computer, to predict the exact tune that a particular drawing would make.

Activity: is TuneTrace deterministic or random?

- Design and conduct your own experiment to figure out whether TuneTrace is deterministic, or whether its tunes are random. Explain what you did, and why you think it would prove whether TuneTrace is really deterministic. What did you find?
- Tip: Often drawings are difficult for TuneTrace to interpret, they can be ambiguous. Turn the screen upside down to see exactly how TuneTrace has interpreted a drawing. See if you can find ways to make drawings as unambiguous as possible.

So, what did you find?

It would be very surprising if you found TuneTrace's result was random. We know TuneTrace is deterministic because its designers made it that way. We know the answer to that one already. But real scientists work on questions to which no one knows the answer. They can't look at an answer key to see if they got the question right. Now is your chance to play with a question like that.

One thing we genuinely don't know about TuneTrace is whether there are infinite tunes. As you've played with TuneTrace, you've probably noticed that some tunes get caught in loops, while others just stop playing. But then there are some tunes that go on for a very long time without stopping or looping. If we left them playing, would some drawings go on forever never stopping or looping?

Super challenge: are some TuneTrace tunes infinite?

- Is it possible to make a drawing that never ends, loops or repeats? Investigate this in any way you can imagine. Try different strategies, and follow your intuition. Keep track of what you try and why, and what you discover along the way.
- Top tip: this problem is really hard. That's why no one, including the person who made TuneTrace, knows the answer yet. So don't feel as though you're under pressure to get it right, or even get an answer at all. The real challenge here, as in all of science, is to ask the right questions, and see where they lead. They might even lead to more questions – that's a good thing. Let your mind go a bit.
- Sharing questions and trying to confirm or contradict the answers by discussing them with your classmates is also useful. In fact science progresses by asking the right questions to disprove the answers to previous questions.

Teacher notes and answers

Here you'll find an explanation of the rules of TuneTrace. This might help if your students come up with theories about some of TuneTrace's rules. Or if they don't believe that TuneTrace obeys rules in the first place!

Later in the notes, we suggest a philosophical discussion about determinism to get your students thinking on a grander scale than the lines and lights of TuneTrace.

How the lights move

- The drawing is interpreted as a *graph* consisting of *nodes* connected by *edges*. Lines are edges, line endings and crossings are nodes (corners don't count as nodes as they're neither an end or a crossing).
- In TuneTrace nodes are labeled with a value that can be either *0* or *1* (the 1s correspond to the lights that appear on drawings). An edge can swap the values of the two nodes it connects. Each edge has a *counter* that keeps track of how many times it has swapped (swapping corresponds to a light moving from end to the other).
- The starting condition is:
    - all nodes that are connected by an edge to only one other node are set to 1, the rest are 0
    - all edge counters are set to 0
- For each subsequent timestep:
    - find all the edges that connect nodes with different values (ie: 1 and 0)
    - from this set find the subset that has the minimum counter
    - in this subset swap the node 1 and 0 values and increase the edge counters by 1

How the lights make music

The musical notes

- If a step results in more lights then TuneTrace plays a higher note
- If a step results in fewer lights then TuneTrace plays a lower note
- If the number of lights stays the same then no note is played.

The percussion

- Percussion works the as same as the notes but based not on the number of lights but on whether a step results in more or fewer edges swapping

Deterministic or random?

None of the instructions are random and so TuneTrace is entirely deterministic. If the same drawing produces different tunes in different photographs then it will be because TuneTrace has interpreted the drawing as a slightly different graph. Turn the screen upside down and you can see the

graph as TuneTrace sees it. If TuneTrace sees exactly the same graph it plays exactly the same tune.

Philosophical fun

One discussion your students might enjoy having is whether the universe is random or deterministic. For centuries scientists, philosophers and theologians have tried to answer the question of whether the whole universe is deterministic, like TuneTrace is. Suppose you knew the setup of every atom in the universe, and all the laws of physics. If the universe is deterministic, you could predict everything that would happen forever. In that case, what happens to our feeling of free will? If your students want to read more about this, look up a short essay by the famous physicist Stephen Hawking called Does God Play Dice?