infusoria without feeling that these little animals are not actuated by some amount of intelligence" [3].

Moving on from protozoa to multicellular organisms, Vertosick described "the intelligence of every living thing" including bacteria [4]. Similarly to Richardson, however, he omitted higher plants that form 99% of the eukaryotic biomass on Earth. Plant behaviour is not strikingly evident because it operates on a totally different timescale to our perception, but its visible aspect is phenotypic plasticity. Higher plants respond to an enormous variety of physical, chemical and biological signals in their environment to maximize foraging for resources in two distinct but unpredictable and variable environments: above and below ground. Optimizing this phenotype probably involves territoriality, self and alien recognition and competition, as described by game theory. Predictive assessments, decisions and trade-offs are all involved, as well as countering the threat of herbivores and disease. Mate selection is elaborate and underpinned by discriminating, complex conversations that precede and follow fertilization.

The goal of any individual plant is the same as that of any animal—the intelligent construction of behaviour to optimize life cycle fitness and maximize selection. To this end, nervous systems are not necessary; complex networks are sufficient to create intelligent behaviour. Higher plant cells are as complex as animal cells, and the individual plant coordinates its millions of cells into overall coherent and intelligent behaviour. Any discussion about the evolution of intelligence therefore has to include the behaviour of plants [5–7].

CONFLICT OF INTEREST

The author declares that he has no conflict of interest.

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Anthony J. Trewavas is at the Institute of Molecular Plant Science, University of Edinburgh, UK.

E-mail: trewavas@ed.ac.uk

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Response to Anthony Trewavas

It is always good to acknowledge the surprising insights into simpler forms of intelligence expressed by scholars a century or more ago. What has not been clear, however, is of what these early forms consisted, how they evolved into the vastly more complex systems we have since seen, and what that might tell us about the nature of these newer forms, especially human cognitive abilities. The "missing heritability" problem, reflecting reliance on additive (independent), and linear deterministic gene effects, suggests that we have been on the wrong track as far as explaining causes of

form and variation are concerned. A better answer, I suggested, arises from challenges posed by increasingly changeable environments as more simple niches became filled. In realistically changeable environments, we need to focus on structures, not elements, in niches, to understand what has evolved. In my article [1] and in other work [2], I have tried to describe the abstraction of structure at increasingly complex levels, based on nonlinear dynamic principles. At all levels, these allow much faster, creative responses to environmental challenges, expanding developmental plasticity and altering evolutionary trajectories. I gave examples in cell signalling and gene transcription systems, in physiological and early nervous systems and in brain, cognitive and human socio-cognitive systems. So we can portray evolution as a series of bridges or cascades, responding to the dynamics in the world at increasingly complex levels, and amplifying potential for complexity in living things. The trend culminated in cognitive powers that transcend the old darwinian laws, in adapting the world to themselves, rather than vice versa.

CONFLICT OF INTEREST

The author declares that he has no conflict of interest.

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Ken Richardson was a Senior Lecturer at the Centre for Human Development & Learning, The Open University, UK. He is now retired.
E-mail: k.richardson@mac.com

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