1) Title: will talk in conceptual terms about information, work and production.
2) Start on familiar ground. Notice the currency for economic system - what should be the currency for the ecosystem?
3) This is the aim of ecological economics, to correctly model the economy as a component of human life, in turn a component of the "ecosystem" - defined as the total of life on earth, and all its interactions, including with its abiotic environment (e.g. global chemical cycles).
4) I think that project has reached this stage, where the relation between ecological and economic systems is understood more as an overlap, or joint system, termed the "socioecosystem". (Note I speculate that the currency for the ecosystem may be energy flow (J).)
5) Here is an example - a popular model termed socioeconomic metabolism, which has much to criticise, especially where the boundary between economy and "environment" is placed.
6) I put it to you that to make progress towards the goal of ecological economics, it may be important to identify a currency that is common to both ecosystem and economy. I believe I have identified one.
7) This illustration shows perhaps the first economic production (evidence of 25,000 y.o took making 'factories' has been reported). What is happening here? The tool shaping is *intentional* - it transforms a naturally random shape into an informed shape with function. It is informed because it is a physical record of the actions of the tool maker and those actions followed a design in the mind of the tool maker (information). Also here, the toolmaker is teaching the next generation - transferring information from one mind to others. Finally, within the body of the tool maker, movements that cause the change of shape of the stone are organised by mental control, which entails information processing and communication.
8) All this leads me to a founding proposition: that *production always entails investing material with information*. We will explore that idea in what follows.
9) Cutting a stone tool involves removal of material so that the shape (initially random) is *constrained* to become informed. This process is *fabrication*.
10) The adjunct to fabrication is assembly - production by *assembly* of components.
11) In this case, a random assembly of components is *constrained* to be a particular assembly that has function. *Particularising, constraining randomness, is always equivalent to adding information*.
12) Information is the constraint of randomness to be a particular arrangement.
13) That works as a definition of information: information is the constraint of randomness.
14) In classic 'information theory' terms, the more you know about a random process, the more that information constrains its probability distribution. If you know it was a 6, then the probability of 6 is increased from 1/6 yo 1 and the probability of all other possibilities is reduced to zero. Information is the converse of randomness and is created by constraining the the probabilities.
15) If we take a random assembly of objects, we can create information by constraining the degrees of freedom over which the objects can be placed.
16) This is how information is made.
17) Let's constrain the location of one object (reducing the degrees of freedom of the assembly). Assume the probability of this constrained assembly is 0.2.
18) When we constrain two objects, the probability is the square of this and we have more information because there is more constraint.

19) With three constrained the probability is cubed.
20) Constraint by a fourth object raises the probability to the power 4.
21) Power 6
22) Power 7 - by increasingly constraining the assembly, we are making the pattern increasingly improbable.
23) Information is embodied in an improbable pattern: when we fix the pattern we invest it with information. It is one pattern out of all possible (which is why it has a low probability).
24) Information is quantifiable. The unit is of course 1 bit.
25) Just to emphasise, here is no information.
26) a single difference is one bit of information.
27) Lots of differences is a pattern and that is information (you can quantify it by counting the differences).
28) This is now an established principle in physics - all information is a pattern in the distribution of matter (or energy). The principle is termed "Landauer's dictum".
29) The term 'information' has three technical meanings: physical, formal and statistical information.
30) We will be concerned only with *physical information* - the pattern in the distribution of matter (or energy), which is the only one that is real.
31) Physical information is embodied by form (the pattern), but also forms that pattern, so there is a logical recursion in which form and information are inseparable. I call this the 'creative recursion'. *Information determines form; form embodies information*.
32-33) Matter plus information = form.
34) Work - the world is more than static forms, work has to be done, if for no other reason that to make those forms.
35) The transition from information to work is one from the static to the dynamic, mediated by flowing energy. Work, i.e. physically doing things, always results from physical causation - let's see how.
36) Every fundamental particle (e.g. electron, proton, muon) has at least one associated forcefield. Things happen (i.e. causation) when these forcefields interact.
37-38) What exactly happens depends on the relative locations of the particles.
39) That of course is what we defined as information.
40) Random assemblies of interacting particles produce heat. When the random force vectors are constrained (information), as in the physical constraint imposed by the cylinder and piston, the forces are *organised* and therefore can do work. Information embodied in the cylinder's form constrains the forces, organising them into a causal action. Physical cause is the same as Aristotle's efficient cause.
41) First Axiom: Production always entails investing material with information.
42-44) The definitive consequences for work and production.
45) It is very important that all these principles apply exactly to biological growth and reproduction - called biological production.
46) The information processing involved in living production is tremendously complicated, but can be summarised - living systems continually invest their material with information.
47) An insight into the amount of information embodied by even the simplest possible living organism. There are around 2000 different proteins each with a complicated - information rich - shape, all interacting in a way that is organised by system-level information.

48) Now let us start applying these principles. We start with the classical view of factors of production.
49) It has become common to add “entrepreneurship”
50) To represent organisation and creative work, marshalling the other factors to productive effect. (Illustration is a beaver making a dam).
51) In an important elaboration of the classical model, Paul Ekins and colleagues produced this one which is highly relevant to ecological economics. Note Land is replaced with Natural capital, Labour with Human Capital and Social Capital, which together also incorporate the idea of entrepreneurship and Capital is more precisely identified as manufactured (physical) Capital. Note waste production and its effect on utility and natural capital.
52) These capitals are important because they provide the capacity to contribute towards the work of production.
53) To understand work as both material production and organisation (entrepreneurship), we need the concept of levels of organisation - a nested structure of patterns of patterns whereby information is embodied at higher levels by constraining the arrangement of lower level entities. Making a portrait out of the arrangement of photos is an illustration.
54) So we can define *organisational work* as the constraint (information investment) of components in a particular (functional) arrangement - here electronic components are fixed relative to one another by the circuit board which embodies circuit level information. My notation is I_p identifies physical information and the level at which it constrains is the index on the right, usually referred to a reference level L.
55) Here is the same thing with engine parts (L) and an engine (L+1) in which all the parts are organised by constraining a random assembly of them to the particular (functional) assembly.
56) To illustrate the generality of this idea, now consider a musical note as an object (level L), so the particular (informed) arrangement of them in a composition is information at L+1. (Note “all the right notes, just not necessarily in the right order” quotes a classic comedy sketch by Morcambe and Wise with André Previn in 1971).
57) Directing a surgical team in the highly coordinated activity of an operation is another example. What is the system level (sL+1) in this case?
58) Now inspect this hospital scene to identify all the ways in which informational work is being done. That covers organisational forms of work.
59) Before progressing, let’s remind ourselves of the four-capitals model of production. Every one of them is there because it contributes a capacity to do work.
60-61) Recall that in general, work is the organisation of energy flows by information.
62) So we can transform the set of capitals into this set of capacities to do work.
63) Every kind of work draws on one or more of the capacities to contribute to work. Here we see human, natural and manufactured capital, organised by cognition and planned intention to organise material into a functional form.
64) Every kind of labour can be decomposed into these factor contributions - every one of which is fundamentally a constraint of energy flow by physically embodied information.
65) Focussing on the builder, consider how more efficient the productive process is when aided by the manufactured capital of the cement mixer.

66) As efficiency of production increases, productivity increases, lowering production costs and thereby increasing demand for the products. All this results in an increase in the total amount of "stuff" in the economy. But the efficiency is gained by increasing the amount of invested information and the result of this cycle is an increase in the total information investment of society.
67) To illustrate, the information embodiment of each historical technology is estimated here: about 1k bits in the flint tool and 1 Gb in the CNC machine. Technical efficiency is directly related to information investment.
68) We can now transform the capacities to work into a set of physical factors of production because in general physical information constrains the flow of energy to produce functional products, including manufactured capital.
69) We can view these, fundamental, physical factors as the latent variables underlying the observed variables as in a principal coordinates analysis. The observed factors of production are shown to be combinations of the fundamental factors.
70) The physical factors of energy flow (J) and physical information (I_p) obey the law of diminishing marginal returns (needed for economic analysis, but inevitable consequences of thermodynamic laws). On the graphs, work output (W) is plotted with J and I_p .
71) Also, J and I_p are mutually substitutable, so we can in principle do economic analysis with them as illustrated with this production function graph. Curves of constant work output are plotted on a J and I_p surface. Recalling that work arises from the constraint of energy flow, the more effectively J is constrained, the more work you get from a given J. To constrain J more effectively, you need more I_p so more informed systems are more efficient. We could use production functions like this to help direct resources away from energy consumption, towards information investment.
72) So if we compare these two scenes of rural production, we can see different trade-offs between J and I_p .
73) In the top scene we see high diversity (information), with relatively low energy flow and in the lower, we see high energy flow and low diversity.
74) Thinking back to the information richness of a single cell, consider if the tractor embodies more or less information than one of the trees making up the biodiversity of the top image.
75) I hope by now you have realised that the common currency I propose for uniting economic and ecological (natural) systems is… physical information.