Simplifying academic knowledge to make cognition more efficient: opportunities, benefits and barriers

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Abstract
Much academic knowledge is unnecessarily complicated and could be simplified, and made easier to learn, understand and use, without sacrificing its power and usefulness. There are many historical examples of such simplifications, ranging from the replacement of Roman numerals by the decimal system, to the beautifully simple theories of Newton and Darwin. This article explores the possibility of further simplifying the knowledge that academics create and disseminate, giving examples from various fields. The benefits, in terms of savings of time and enhancement of the power and accessibility of academic knowledge, are potentially enormous.

Keywords: Academic knowledge, Public understanding of science, Simplicity, Simplifying knowledge, User-friendly mathematics.

Contents

There is more on this theme at http://woodm.myweb.port.ac.uk/SL/simplelearning.htm.

Introduction

It is a well worn platitude that life is getting more complicated. In the academic world this is reflected in the increasing amount and complexity of the knowledge that academics discover or create, and pass on by teaching, books, articles and other media. The amount and complexity of this academic knowledge places obvious constraints on what we can achieve, both in our academic work, and in our day to day life. Specialists only have a limited amount of time to master their discipline, and aspects of other fields of study relevant to their work. And the access of lay people to knowledge on, for example, medicine, is limited by the time they have to research the intricacies of the various specialisms. (My concern in the present article is with the rather vaguely defined category of academic knowledge, of which science is a similarly vaguely defined, but important, sub-category. I am using the term knowledge to cover concepts and conceptual frameworks, theories, facts, hypotheses, etc.)

There are a number of obvious approaches to this problem: improving learning and educational methods, using technology to enhance the effectiveness of human thought processes via computer technology or smart drugs, increasing the time devoted to education, and so on. In this article I want to explore the possibility of tackling the problem from the other end by simplifying knowledge itself.

I had difficulty formulating an appropriate title for this article. The word "simple" provides a convenient slogan, but, as we will see, the idea is not itself a simple one. The phrases "more appropriate for its context", or "better integrated into common sense", or "more fit for purpose" give a more accurate picture of what I have in mind . I eventually decided to keep the word simple, but to qualify if with the phrase "to make cognition more efficient" because this gets over the idea of achieving as much with less effort, or achieving more with the same effort. (By "cognition" I mean the whole process of learning, understanding and reasoning.) Earlier phrases I wondered about were "to empower the ignorant" and "to empower the masses": these are both consistent with what I have in mind, but suggest that the market for the idea is limited to the ignorant, the lazy and the stupid, which is not at all what I intend.

I have come to the general idea of simplifying knowledge via several interlinked routes:

1. There are historical examples of simplifications which have had enormous and obvious benefits - such as the adoption of the decimal system of numerals and the metric system for weights and measures.
2. When teaching topics in statistics, research methods and quality management, it has often occurred to me that the material I am teaching could be simplified while preserving its usefulness. Sometimes the conceptual base could be changed, sometimes the jargon could be made more transparent, sometimes I could ignore conventions decreeing the teaching of approaches which have been superseded, and so on.
3. Simplicity is a key criterion for evaluating, and so creating and choosing, scientific theories.
4. Simplicity is an important criterion in the design of technological artefacts, and academic knowledge can be regarded as such an artefact.
5. A person's understanding of almost anything typically has holes in it. Nobody knows everything about how to make a pencil or how a computer works; similarly my knowledge of the t-test in statistics does not include details about how the t-distribution

is derived. Ideas can be simplified by leaving out inessential details. Knowledge is holey and the location and nature of the holes deserves careful consideration.

6. Computer technology provides a massive enhancement of our ability to calculate and search. The fact that these tasks are now trivial has important implications for what is worth knowing.
7. If we take an evolutionary perspective on knowledge, the main criterion which new ideas have to satisfy is that they should be useful - either in the biological sense of enhancing the capacity of the organism to survive and breed, or in the cultural sense of their usefulness to individuals and groups - and knowledge is likely to be more useful if it is simple (other things being equal). Unfortunately, incremental evolution has a tendency to lead to increased complexity (Cohen and Stewart, 1995, 135-8), which suggests the idea that intelligent design for simplicity might be beneficial.
8. Finally, simplification is a natural and necessary part of the way human beings make sense of the world. Concepts like "animal" and "rock" enable us to manage our environment without plunging into all the overwhelming complexity of the different types of animals and rocks.

Despite searching on the obvious keywords using Google and Google Scholar, and checking through the first twenty or so hits, I found very little on the general idea of simplifying academic knowledge. In an earlier paper (Wood, 2002) I focused on the idea of simplifying knowledge from the educational perspective, and the barriers to the idea that are likely to be imposed by educational systems. In the present article I want to extend this argument, and take a more general perspective.

Perhaps the closest to the general thesis I have in mind are the various campaigns, courses and publications on the theme of simplicity run by Edward de Bono - e.g. de Bono (1998) and the website at http://www.debonogroup.com/simplicity.php. These concern simplicity in all walks of life, but there is little on academic knowledge as such.

There is a lot of academic research, and other material on the web, on the subject of simplicity in science in general, and specific topics in particular (often with titles like a "user-friendly approach to ..."), and on the design of artefacts of various kinds. Most of this is too specific for my purposes here, but an exception is the material on philosophy of science - see, for example, the summaries by Baker (2010) and Fitzpatrick (undated, accessed on 30 September 2015). Simplicity, in the sense of reducing the number of entities or principles posited as far as possible, is widely regarded as a virtue in scientific theories. Baker (2010) gives several similar quotes from scientists including Einstein: "the grand aim of all science…is to cover the greatest possible number of empirical facts by logical deductions from the smallest possible number of hypotheses or axioms." This may describe Einstein's approach, and that of many other scientists, and as a tactic for generating fruitful theories it may make good sense, but as Baker's (2010) review makes plain the arguments for simplicity, from a philosophical point of view, are varied and not conclusive. For example an opposing "principle of plenitude" may sometimes be preferable: "Our best current theories presumably do not rule out the existence of unicorns, but nor do they provide any support for their existence. According to Occam's Razor we ought *not* to postulate the existence of unicorns. According to a principle of plenitude we *ought* to postulate their existence."

What these philosophical arguments largely omit is the user's perspective. Although Fitzpatrick undated) says that simpler theories "might also be easier to understand and to work with", this is an afterthought and is not followed up. Simplicity is viewed as a property of the knowledge itself, not of the user's relationship with the knowledge - which is the perspective that is important for my purposes here. Simplicity in the sense of a number of entities of one type or another may still be relevant, but users' familiarity with these entities is likely to be of greater importance. There is a brief discussion of this perspective on simplicity in Cycleback (2010, p. 157), and it is implicit in the penultimate sentence of the preface to the third edition of Simon's (1996) *The sciences of the artificial*: "... I propose that the goal of science is to make the wonderful and the complex understandable and simple - but not less wonderful."

Another strand of the simplicity literature concerns the design of products of various kinds. Again, most of this is too specific to be relevant for my purposes here, but one exception is the TED talk by Whitesides (2010). He makes the point that there is almost no drive for simplicity in the academic world, whereas in "the real world of people who make things ... there is an intellectual merit to asking: How do we make things as simple as we can, as cheap as we can, as functional as we can and as freely interconnectable as we can?" He also uses the word "stackable" - electronic components are simple in the sense that they are sufficiently reliable and predictable to be assembled into devices like mobile phones, and blocks of stone can be stacked to build a cathedral. If we think of academic concepts and theories as "things", I would say there is enormous merit in asking just the same questions of academic creations.

There are many text books in every discipline which aim to communicate their subject matter in as simple a way as possible, as well as research on teaching and learning. Sinatra et al (2014), for example, discuss "conceptual change" as a tactic for "addressing challenges to public understanding of science": the change in question, however, refers to changing the public's conceptual framework, rather than adapting the scientific framework as I am proposing here.

My purpose here is to explore the possibility of simplifying mid-range knowledge - between common sense concepts like animals and rocks and the primary (elementary) school curriculum on the one hand, and the cutting edge of science like the search for a theory of everything on the other. This raises two obvious questions - are such simplifications possible, and what is meant by simplification? The next section considers some specific examples to help answer the first question, the section after discusses the second question, the one after that looks at the other side of the coin - the problem of over-simplification - and finally I will look at the potential benefits of and barriers to making knowledge simpler.

Simplicity and appropriateness for purpose: some examples

There are strong pressures for simplification in some areas of knowledge. The pressures of the market mean that software (which can be regarded as an extension of the human cognitive frame) is now generally much more user-friendly than a few years ago. As we have seen, there is a pressure for simplicity at the cutting edge of some sciences. And, despite the efforts of pedants, language continues to evolve as circumstances change (e.g. CU as a shorter text message version of "see you"). However, one area where are few effective pressures for simplification is academic knowledge, except at the leading edge of research, and a few isolated examples.

One such isolated example is the fact that the "activity on arrow" (AOA) method of project planning has been largely superseded by "activity on node" (AON) because "activity on node diagrams are generally easier to create and interpret" (Wikipedia article on "Program evaluation and review technique" accessed on 20 September 2015). This is a small corner of the knowledge taught in universities and colleges, mainly to project managers who may use the technique in their jobs. Although I remember a colleague who was determined to stick with AOA, the obvious virtue of the extra simplicity of AON has won the day.

However this is an isolated example: the victory of the simple version is perhaps helped by the fact that the technique is typically implemented by software and software sales are helped by user-friendliness, and by the fact that the only purpose in learning about the technique is the practical one of planning projects and there is no requirement for consistency with other aspects of academic knowledge. In most areas of academic knowledge there is no tradition of trying to design simpler (or more appropriate for the context and audience) versions of well-known concepts, techniques or theories.

In the remainder of this section I will give a few suggestions about how some topics might usefully be simplified. The point of looking at these examples is to illustrate the principle that simplification is possible, not to establish how widespread this possibility is. To simplify something usefully requires a thorough understanding of the area (as de Bono, 1998, p. 283 points out), so my examples are all in areas I know about. There will almost certainly be similar examples in other areas. Equally obviously, whether a proposal is a genuine simplification, taking account of the audience and the context, is at root an empirical question, so these illustrations should be regarded as unproven hypotheses. But the potential benefits are such that I think the case is worth arguing despite these provisos.

The examples below may seem haphazard and some of them may seem trivial and not worthy of serious research, but the point is precisely that seemingly trivial tweaks to standard ideas in a broad range of contexts could have a massive impact. The examples below do have a mathematical bias because this is where I see the most serious problems when teaching, but the principle is much broader.

Sometimes knowledge can be simplified by ignoring anything that adds no value. Whitesides (2010) quotes Antoine de Saint-Exupery: "You know you've achieved perfection in design, not when you have nothing more to add, but when you have nothing more to take away." When the elusive Higgs boson particle was finally detected by researchers at CERN the result was described as having "a statistical significance of five standard deviations (5 sigma) above background expectations. The probability of the background alone fluctuating up by this amount or more is about one in three million" (from the CERN website in April 2015). The essential figure here is one in three million: the 5 standard deviations is very difficult to make sense of and adds nothing at all to the argument or the conclusions. Obviously this is a trivial point, but the danger is that the audience's attention will be deflected from the Higg's boson to the essentially pointless issue of what five sigmas means.

Very similar issues arise in industrial quality control which has the same tendency to use sigmas (standard deviations), or statistics derived from them such the capability index, c_{pk}, instead of more straightforward quantities like "parts per million out of specification" (Wood et al, 1998).

Jargon is often a problem. Sometimes it is overly complicated, sometimes it has no relation to the audience's frame of reference, and sometimes jargon may be likely to mislead. The term "significant" as used in statistics is a good example of potentially misleading jargon. Consider the conclusion that "orthoptists in the GSC [German speaking countries] preferred using spectacles plus occlusion as their first choice treatment, significantly more than their UK counterparts who preferred spectacles only as their first choice ($p<0.001$)" (Tan et al, 2003). Interpreted as ordinary English, the word significant implies that the difference between the GSC and the UK is a large one. Statistically, however, this is not the meaning at all: the word significantly means that the results obtained in the study were unlikely to have arisen if there were no systematic differences between the GSC and UK - a convoluted concept which makes the misinterpretation of the word "significantly" almost inevitable. The design of transparent jargon to avoid such problems should be a flourishing area of research - which, to the best of my knowledge, it isn't.

There is a very extensive literature on the problems with the idea of significance and statistical null hypothesis testing (e.g. Nickerson, 2000). A common recommendation is to express results in terms of confidence intervals instead of significance levels (Gardner and Altman, 1986); another possibility is confidence levels for hypotheses (Wood, 2014). There are many other areas of statistics where the conceptual base, as well as the jargon, could usefully be revised - e.g. the mean deviation from the mean is more robust and interpretable than the standard deviation (Taleb, 2015, pp. 16-17, accessed on 12 October 2015).

On a much more extensive scale, many traditional statistical models can now be replaced by computer simulation methods which are conceptually far simpler (Simon, 1992; Wood et al, 1999, Wood, 2005a; Wood, 2005b).

According to Wikipedia (accessed 22 September 2015) the estimated annual growth rate of the population of the world was 1.1% in 2009. The standard mathematics then predicts that, if this growth rate is continued over the next 100 years, the population would be multiplied by a factor of

$$e^{0.011 \times 100} = e^{1.1} = 3.00 \text{ (to two decimal places)}$$

so the growth over 100 years would be 200%.

How long would the population take to double (grow by 100%)? The standard mathematics then involves finding x to satisfy the equation

$$e^{0.011x} = 2$$

which means that $0.011x = \log_e(2) = 0.693147$, so $x = 0.693147 / 0.011 = 63.0$ years (to one decimal place).

This mathematics is used in many fields of inquiry (e.g. population studies, economics, genetics, reliability theory), but many users are likely not to be familiar with the background of calculus and the theory of logarithms. They may have difficulty implementing the functions on a calculator or spreadsheet, and will certainly have little idea how they are derived or what the rationale behind them is.

This suggests the possibility of redesigning the concepts involved to make them independent of calculus and the theory of logarithms, and as comprehensible as possible from the perspective of non-expert users' background knowledge. My suggestions are on the spreadsheet at http://woodm.myweb.port.ac.uk/SL/compoundgrowth.xlsx and described in the document at http://woodm.myweb.port.ac.uk/SL/compoundgrowth.pdf. They use two core concepts: *proportional growth with no compounding* (or *pgnc*) and *proportional growth with continuous compounding* (*pgcc*). In the first example above *pgnc* is 110% (100x1.1%) and *pgcc* is 200%, and the spreadsheet enables users to go from one to the other. (In conventional terms $pgcc=e^{pgnc}-1$.)

Using these concepts is by no means trivial: they do after all deal with limiting processes and subtly different definitions of growth rates, but they do have the advantage of showing the relationship between the two concepts in a direct and transparent manner (try adjusting the number of steps in the yellow cell in the spreadsheet) without introducing extraneous ideas from calculus and theory of logarithms. This suggested approach is in no sense an approximation or less rigorous than the standard version; it simply focuses on a different, and I would argue more appropriate, set of core concepts.

These are just a small selection of examples to illustrate the principle. There are further examples in Wood (2002) and at http://woodm.myweb.port.ac.uk/SL/simplelearning.htm.

Assessing simplicity

Wood (2002) suggested eight principles for simplifying knowledge: one, for example, is "conceptual re-engineering" (like my suggested reengineering of the theory of population growth in the previous section), and another is "minimum value" which means ignoring anything which fails to add sufficient value (like the sigmas in the above section).

Here I want to address the more fundamental question of how simplicity can be assessed. This is not, and cannot be, simple. Normally we evaluate the simplicity of knowledge in the abstract without reference to users and uses: unfortunately taking account of these complicates the issue massively. All I can do here is mention some of these complications.

Most obviously, simplicity only makes sense in relation to a particular audience. For someone with a reasonable knowledge of mathematics, the exponential function and natural logarithms may be simpler than *pgnc* and *pgcc* (see above); for someone without such a knowledge, the opposite may be true.

But then, we might argue, a crash course in conventional mathematics for the non-mathematician may be the best answer because this will give them access to other equations. Against this there is the time and effort involved, and the fact that they may not want such a crash course. Analyzing which is the better option needs to take account of the time and effort involved in learning and using each framework, and the benefits gained or the pain endured. Further, there may be differences in terms of the likelihood of making errors.

Assessing the simplicity of a new piece of knowledge, in the sense of appropriateness for the purposes of specific users, needs to take account of the following issues (at least):

1. The existing knowledge of the prospective audience - what concepts, skills and techniques are they familiar with?
2. The generality of the new knowledge: does it just enable users to do just one new thing, or a whole range of possibilities?
3. Does it require a lot of time and effort to learn, or can it be picked up as it is used? Is it easy to use?
4. Is it likely to lead to errors, or can users be confident they are right?
5. How much insight does it give users into the justification of the knowledge, into why it should be accepted? The compound growth framework involving the concepts *pgnc* and *pgcc* is, I would say, far more likely to provide such insight than a superficial understanding of exponential functions and natural logarithms and calculus (see above). Such insights are important for many reasons - e.g. in that they are likely to make errors and misinterpretations less likely.

Clearly assessing each of these dimensions in a particular situation would not be easy, especially as, with the possible exception of (2), they are all empirical questions requiring evidence about real people doing real tasks. The resulting interpretation of simplicity is multidimensional and may require the balancing of pros and cons on different dimensions.

The problem of over-simplification

Obviously, the simpler knowledge is the better, provided the simple version is at least as good as the complicated version. However, the difficulty is that the simple version may sometimes be a lot worse: it may be a very rough approximation, misleading, useless or simply wrong. Let's look at a few examples.

Simple statements like "The Swiss are much happier than Nigerians", or "Exposing yourself to strong sunlight is a bad idea" or "There are two types of social research - quantitative and qualitative", or "Britain could derive a huge amount of energy from renewable sources" are - for many purposes - oversimplified and potentially very misleading. Some Swiss are doubtless much more miserable than some Nigerians; the generalization just refers to averages. People who don't expose themselves to any sunlight run the risk of vitamin D deficiency. If you think there are only two types of social research you will probably identify the analysis of subjective feelings with the qualitative pole, ignoring the fact that there is a whole industry based on assessing subjective feelings on 1-5 scales analyzed with quantitative statistics (Wood and Welch, 2010). And it is not enough to know that the potential of renewables is "huge"; we also "need to know how it compares with another 'huge,' namely our huge consumption" (MacKay, 2008). The use of adjectives like "huge" oversimplifies the problem: "to make such comparisons, we need numbers, not adjectives."

Politicians need neat soundbites like "we must balance the budget" because "the economy is like a household", which of course it isn't. This is an over-simplification, but any more nuanced view would be unlikely to have as much impact with the electorate. Which is a problem.

In 2008 the world economy plunged into a crisis triggered, according to Silver (2013), largely by over-simplified, and horribly inaccurate, measures of risk. Banks and other financial institutions buy and sell securities like mortgages, and they obviously need an estimate of the risk of losing their money on these transactions. In practice, estimating these levels of risk is a complicated task, so they simplify the problem by using the assessments of rating agencies - these organizations categorize risk into bands. AAA, for example, is intended to mean a probability of default of 0.12%, but during the crisis 28% of these securities defaulted. This led to losses far greater than expected, and to the necessity to bail the banks out and all the other consequences of the crisis.

So, even organizations whose job was to manage financial risk felt the need to use simplified measures provided by a third party. And the reason that the risk assessment were wrong was that the ratings agencies over-simplified the task of making these assessments. They made an assumption - that the component risks were independent of each other - which was a long way from the truth, leading to a massive under-estimate of the risk of defaulting. This was an elementary mistake, but without it, the task of assessing risk becomes difficult and the answers become vaguer, so the temptation to make the simplifying assumption was probably overwhelming. Perhaps with a more thorough understanding of how the probability theory works these mistakes would have been less likely?

There are many ways in which we can oversimplify things but it is worth mentioning one which seems to appeal to the academic mindset: over-extending or oversimplifying appealing concepts. As discussed in the previous section, the concept of simplicity itself is far more multifaceted and problematic than my use of it as a slogan might make it appear. And any sort of measurement - whether a number measurement, or a subdivision into two or more categories (simple / complex, qualitative / quantitative, left wing / right wing, heavy drinker / light drinker / teetotaler, happiness measured as a number, etc) - runs a serious, and often unacknowledged, risk of over-simplification. Simplification is a powerful and seductive tool of thought, but we need to be very careful.

Over-simplification is certainly a problem. But the cause is often that a more appropriate understanding is too complicated to make sense of, so we may have little option but to go for the crude and unhelpful over-simplification. Complicated knowledge may push us into dumbing down. The remedy is dumbing up: sensible and thoughtful simplification.

Conclusions

Conventionally, academic knowledge is viewed as a given, which should not be fiddled with to suit the requirements of users and the context of use. I think this is a mistake: it should be designed, or redesigned, to make it as simple as possible for the context of use. We have looked at a few examples where knowledge might usefully be simplified. These are just a few areas I know something about: there are likely to be many similar opportunities across the whole spectrum of human knowledge.

The benefits brought by such simplifications are potentially enormous. Let's imagine that some difficult knowledge can be simplified by a factor of about a quarter. (I think in many cases this could be nearer 50% or 75%.) This might mean that people spend 25% less time learning about it, or using it, or that the simplification means that they can master 25% more than they would otherwise have been able to, or that they make 25% fewer mistakes, or that 25% more people are able to master it. Over the whole spectrum of difficult knowledge this has the potential to make an enormous difference. Imagine that students around the world could spend 25% less time on their studies. The rest of the time could be spent taking their studies further, or doing something completely different. And researchers would arrive at the frontiers of their discipline sooner, or with a better understanding of other relevant areas, both of which should lead to faster progress.

Why isn't this happening already? The main reason is probably that nobody seems to have pursued, the idea as a general principle, perhaps because of the assumption that academic knowledge expresses the truth, and truth is fixed and not adjustable to suit the circumstances. Or simply because the only people in a position to produce a useful simplification are the experts in the domain who are unlikely to see the need - for them the expertise is trivial and an essential part of the discipline. Further, they have an interest in keeping their subject sufficiently complicated to protect their status as experts. Like all paradigm shifts, the most likely champions are outsiders, but outsiders may not have a sufficiently deep understanding to create a viable alternative.

But whatever the reason, the idea of simplifying knowledge does not seem to be on anybody's agenda. This lack of interest is reinforced by the complete absence of academic journals on the theme of simplification. To get published an academic need to produce something complicated; a simple version of an existing idea is rarely viewed favorably by the gatekeepers of academia. There is also the conservative influence of the education system, and the attitude of teachers at all levels that "standards" should be maintained, that knowledge should not be "dumbed down", and that, in the words of a *Daily Telegraph* leader column "maths should be hard" (Wood, 2002).

I would like to see simplification on the agenda. Three projects, in particular, appeal to me. The version of statistics taught on the academic curriculum is a major source of confusion and incomprehension in urgent need of reform. I would love to understand quantum mechanics at a deeper level than I do, but I think I need to wait for a version more in tune with my aptitudes and the time I have available. And medicine needs a rigorous, reduced-jargon makeover.

If we don't start to simplify our increasingly complicated web of knowledge, human progress will slow down or cease as our minds become clogged with unnecessary technicalities, and inevitable over-simplifications take control of our thoughts and actions. We need to see the design of elegant, fit-for-purpose, perspectives as an important task for academia.

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