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Science, abduction and the fuzzy nurse: an exploration of expertise

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Science, abduction and the fuzzy nurse: an exploration of expertise
Benner's work on expertise in nursing drew heavily on the writing of Dreyfus and Dreyfus in the field of computing. Dreyfus and Dreyfus argued that the continued failure of computer programmers to create an 'expert system', a program which could replicate the way that a human expert thinks, implied that experts do not think in a rational, analytic way. Dreyfus and Dreyfus therefore concluded that expertise is an intuitive process, and that 'the expert is simply not following any rules! He is… recognising thousands of special cases'. Applied to nursing, this model of expertise has a number of profound implications for practice and education, and has been criticised for being elitist and deliberately obscure. This paper examines some recent innovations in computer logic, and argues that nursing can learn from a new breed of 'fuzzy' computer programmes which appear to be able not only to perform *better* than experts, but to verbalize their decision-making processes. By beginning to understand how experts think, it might be possible to develop expertise in a more controlled and logical way, thereby improving the practice of nursing.

EXPERTISE

Patricia Benner's influential book *From Novice to Expert* (Benner, 1984) drew heavily on a concept of expertise which derived from work by computer scientists into artificial intelligence. This paper attempts to explore those roots of expertise, and to examine how current breakthroughs in the field of computing might enable us to develop the concept of the expert nurse further. However, the recognition of expertise can be traced back to long before the invention of the computer, and this paper therefore begins with two quotations which illustrate the longstanding intransigence of the problem of attempting to describe expert behaviour. The first is from a Chinese wheelwright living in the fourth century BC, and the second is from a modern-day American computer scientist.

First, the wheelwright, whose words were recorded by the philosopher Chuang Tzu

> In making a wheel, if you work too slowly, you can't make it firm; if you work too fast, the spokes won't fit in. You must go neither too slowly nor too fast. There must be co-ordination of mind and hand. Words cannot explain what it is, but there is some mysterious art herein. I cannot teach it to my son; nor can he learn it from me. Consequently, though seventy years of age, I am still making wheels in my old age.
>
> (Chuang Tzu, Trans. Giles 1926 p. 140)

Now, the computer scientist (and his philosopher brother)

> Problems involving deep understanding built up on the basis of vast experience will not yield — as do simple, well defined problems that exist in isolation from much human experience — to formal mathematical or computer analysis
>
> (Dreyfus & Dreyfus 1986 p. 11)

Inability to explain

What these writers have in common is a great respect for, but an inability to explain, expertise. 'There is some mysterious art herein', which 'will not yield… to formal

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mathematical or computer analysis'. The only real difference in what they are saying is the span of time which separates them.

The second quotation is of particular relevance for nursing, because Benner's work was based largely on Dreyfus & Dreyfus's critique of 'expert systems'. The Dreyfus brothers, a philosopher and a computer scientist, argued that expert systems, computer programs designed to reproduce expert behaviour, were inherently flawed because they looked at the whole concept of expertise in the wrong way. Expert systems capitalised on the large storage capacity and very fast processing times of computers by feeding them with thousands of rules and heuristics which the computer would rapidly run through until it found the one which worked best.

For example, a computer chess expert runs through thousands of moves a second, projecting several moves ahead, and chooses the move which has the most likelihood of success. An expert computer aircraft pilot computes the outcomes of thousands of manoeuvres and chooses the safest but Dreyfus & Dreyfus argued that real-life experts do not work in this way. The chess grandmaster intuitively knows the right move to make; the expert pilot simply makes the safest manoeuvre without thinking; neither of them have the time to work out all the possible moves, they just seem to know the best one. As Dreyfus & Dreyfus pointed out

> an expert's skill has become so much a part of him that he need be no more aware of it than he is of his own body.
>
> (Dreyfus & Dreyfus 1986 p. 7)

Application to nursing

Benner applied this analysis of expertise to nursing. Novices, she argued, function in the same way as computer expert systems, although without the advantage of the vast memory capacity and enormous speed of the computer, by applying previously learnt 'context-free rules to guide action' (Benner, 1984 p. 21). Novices nurse by the book, either by following written procedures where these exist or by basing their practice on what the textbooks and research papers tell them is the best course of action in any general case. For example, when nursing a patient who is due to have surgery, the novice will provide him with information about his operation because research has demonstrated that this decreases the need for post-operative analgaesia and promotes healing.

In contrast to this rule-following approach, for the expert nurse, like the chess grandmaster, the correct response to a clinical problem just seems to appear out of nowhere and cannot always be justified. Benner demonstrated this by quoting an expert psychiatric nurse

> When I say to a doctor 'the patient is psychotic', I don't always know how to legitimize the statement. But I am never wrong. Because I know psychosis from inside out. And I feel that, and I know it, and I trust it.
>
> (Benner 1984 p. 32)

Intuition

The expert nurse bases her decision on what Dreyfus & Dreyfus called intuition. This concept of intuition was, for Benner, at the same time a blessing and a curse. It was a blessing because it explained the differences between the novice and the expert and pointed to experience as the defining factor in expertise, since intuition is 'available only in situations where a deep background understanding of the situation exists' (Benner, 1984). However, neither Benner nor Dreyfus & Dreyfus could explain precisely how the expert nurse makes decisions.

Intuition should not, Benner claimed, be confused with mysticism, but it nevertheless remained 'some mysterious art' which more than two thousand years had failed to illuminate. The curse, then, is that experts seem to rely on an intuitive process which cannot be verbalised and which computers appear not to be able to imitate. Expert knowledge is, in Polanyi's phrase, 'tacit knowledge' (Polanyi 1962), and as the Chinese wheelwright pointed out, 'words cannot explain what it is'.

SCIENCE

The foundation of the logic around which the whole of Western science is built was laid down by Aristotle over two thousand years ago, and is based on the simple syllogism

Premise	All men are mortal;
Premise	Socrates is a man;
Conclusion	Therefore Socrates is mortal.

The syllogism is an analytic statement: it introduces no new knowledge. Providing that the two premises are true, then the conclusion *must* logically follow. This same pattern of reasoning is echoed in the formal scientific research process, which Popper (1973) has termed 'hypothetico-deductivism'. We start with a hypothesis: pre-operative information-giving promotes healing. We then attempt to falsify that hypothesis by carrying out a controlled and systematic collection of data, perhaps by sending out questionnaires or making observations. If we are unsuccessful in falsifying our hypothesis, then it is provisionally accepted, promoted to the status of a theory, and is said to be generalizable, that is, applicable to all cases represented by our research sample.

Process of deduction

Our general theory that information-giving promotes healing can now be applied to individual cases through the logical process of deduction. Thus

Theory	Pre-operative information-giving promotes healing;
Individual case	This patient is having surgery tomorrow;
Deduction	We should give him information about his operation in order to promote healing.

This is research-based practice and it lies at the heart of the British Government's strategy for nursing, that 'all clinical practice should be founded on up-to-date information and research findings' (Department of Health 1989 p. 2). The same logic is employed to programme digital computers, where it forms the basis of algorithms. Algorithms are simple *if-then* decision making processes by which computers reason. For example

If a patient is going for surgery, *then* we will give him information about his operation.
This patient is going for surgery.
Therefore we will give him information about his operation.

Novice practice

This approach to clinical decision-making is, by both Benner's and Dreyfus's definitions, clearly novice practice, 'the manipulation of unambiguously defined context-free elements by precise rules' (Dreyfus & Dreyfus 1986 p. 73). Dreyfus & Dreyfus argued that because expertise defied this kind of simple analysis and could not be expressed in terms of the formal logic which is employed by computers and scientists, then the process which delivers expertise is essentially unknowable. 'The expert is simply not following any rules! He is… recognising thousands of special cases' (Dreyfus & Dreyfus 1986 p. 82). Or, as Benner put it

> Capturing the descriptions of expert performance is difficult, because the expert operates from a deep understanding of the total situation.
>
> (Benner 1984 p. 32)

Dreyfus & Dreyfus's argument that the process of expertise is unknowable, is therefore based largely on their objections to expert computer systems. Thus

> no matter how much more work was done in computer simulation and operations research, and no matter how sophisticated the rules and procedures became, such analytic abstractions would never allow the computer to attain expertise.
>
> (Dreyfus & Dreyfus 1986 p. 10)

Computers, they argued, can never be programmed to fly an aircraft in the way that an expert pilot does because the expert pilot is not following any logical rules; he is flying by intuition.

ABDUCTION

However, a new generation of computer scientists, employing what they call 'fuzzy logic', claims to have solved the problem of expert systems. The following quotation comes just eight years after Dreyfus & Dreyfus claimed that a computer would never fly!

> Professor Michio Sugeno of the Tokyo Institute of Technology has built a fuzzy system that can stabilise a helicopter in flight when it loses a rotor blade. No human can do that and no known math model can do that. Sugeno's system uses about 100 rules. He has tested it on a three-meter model and wants to test it on the real thing.
>
> (Kosko 1994 p. 170)

The breakthrough has come about because the computer is programmed not with the black-and-white rules of formal analytic logic, but with 'fuzzy rules', which use vague and imprecise instructions such as 'a bit to the left' or 'slightly higher'. In simple fuzzy systems, the computer is programmed with the verbalized rules of experts.

> 'A fuzzy engineer may sit down with an expert and ask her how she focuses a lens or makes a left turn or steadies a helicopter'.
>
> (Kosko, 1994 p. 39)

But as we have seen, more often than not the expert is unable to verbalise her expertise.

Intuition again

Dreyfus & Dreyfus (1986) interpreted this to mean that there *were* no rules being employed, only intuition. Kosko and the fuzzy computer scientists interpreted it as meaning that there were rules, but that they were just too fuzzy or imprecise to be expressed by language. The breakthrough came when Kosko wrote a programme which enabled the computer to learn from what experts *do* rather than from what they say.

> Adaptive fuzzy systems 'suck the brains' of experts. Experts do not have to tell the system what makes them experts. They just have to act as experts. This gives the data that the neural nets use to find and tune the rules.
>
> (Kosko 1994 p. 39–40)

The computer therefore has access to the same accumulation of experience, the same thousands of special cases, as Dreyfus's human experts. Furthermore, it generates its own fuzzy rules based on those experiences *and* is able to verbalise them.

But if the computer is not employing formal analytic logic, then how is it solving problems? Fuzzy rules, unlike the formal rules of logic, are imprecise. Logical problem-solving is based on linear chains of *if-then* algorithms: If A, then B; if B, then C; if C, then D; and so on. Fuzzy problem-solving, however, is a parallel process. All the rules apply at once, but to different degrees, depending on the situation, and we take what Kosko calls a 'fuzzy weighted average' of all the different rules

> You add up a lot of things and weigh each thing to some degree. Then you go with the average or 'centroid' or center of mass. You do not solve math equations or draw rule patches on a page. You do it by feel. You feel or intuit the center of mass. It pulls you or inclines you. After a life of this you are good at going with your mind's flow.
>
> (Kosko 1994 p. 176)

We are back to intuition again, but this time it is intuition based on rules, albeit fuzzy rules. For Kosko, this was enough.

> If our reasoning has logic, it's fuzzy at best. We have only one decision rule: *I'll do it if it feels right*. The formal logic we first learnt in tenth-grade geometry class has little to do with it.
>
> (Kosko 1994 p. 17)

Kosko is right to reject formal logic, but, I believe, wrong to reject logic completely. Indeed, his 'fuzzy weighted average' of all the fuzzy rules which an expert employs is itself a form of logic. But whereas the precise rules of science are chained together by the formal analytic logic of hypothetico-deductivism, the form of logic which best describes the weighing-up of fuzzy rules is the logic of abduction.

Little-known form of reasoning

Abduction is a little-known form of reasoning proposed by the nineteenth century philosopher Charles Peirce (Peirce 1958, Hanson 1961. See also Garnham & Oakhill 1994 for a clear and simple exposition of abductive reasoning). As a pragmatist, Peirce argued that whereas formal deductive logic starts with a general statement or theory about the world, such as 'all men are mortal', or 'pre-operative information-giving promotes healing', in real life we usually start with a problem concerning an individual, such as 'is this man mortal?' or 'should I give this patient any pre-operative information?'. Abductive reasoning therefore turns formal logic on its head by beginning with the conclusion and arguing backwards to the premise. For example, a simple deductive syllogism would argue as follows

cars need petrol in order to go
my car has no petrol
therefore, my car will not go.

In contrast, an abduction would take the form

my car will not go
cars need petrol in order to go
therefore, my car has no petrol.

In terms of formal propositional logic, this argument is flawed, since there are any number of premises that will explain this problem (no petrol, a flat battery, a broken starter motor, and so on), and so we need to apply our general knowledge about cars, and our personal knowledge about *this* car in *this* situation, in order to select the most likely premise. I might know, for example, that my car has a new battery and starter motor, but that the fuel gauge is inaccurate, and that it has been quite a while since I last filled it with petrol. The plausibility of my explanation therefore depends to a large extent on what I know about cars in general, and how well I am acquainted with the individual workings of my particular car.

Formal logical syllogisms use only the information included in the premises. *If* cars need petrol in order to go, and *if* my car has no petrol, then logically, it will not go. Abductive reasoning, however, makes use of a wide range of information which is not formally stated. Whereas formal syllogistic reasoning progresses by logical steps, abductive reasoning throws a number of fuzzy rules at the problem all at once. A car needs a well-charged battery and a fairly reliable starter motor, as well as a reasonable amount of petrol in order to go. By combining these rules with what I know about my car, I can take a fuzzy weighted average and abduce that the most likely cause of the problem is a lack of petrol.

THE FUZZY NURSE

The promise of artificial intelligence in the 1970s was that, by studying how computers solved problems and made decisions, we could better understand how humans functioned. That promise ultimately led to disillusionment, as it became more and more obvious that people did not process information in the linear, logical, *if-then* chains of reasoning employed by digital computers. In particular, the study of computer expert systems led scientists and philosophers alike to the conclusion that we could *never* understand expertise, and that 'no amount of rules and facts can capture the knowledge an expert has when he has stored his experience of the actual outcomes of tens of thousands of situations' (Dreyfus & Dreyfus 1986 p. 83).

Recent advances in computer science, however, suggest not only that we are beginning to understand the logical processes involved in expertise, but that expert behaviour can be reproduced using relatively few rules. The breakthrough was in how those rules are conceptualised. Dreyfus and Dreyfus were quite right in asserting that no amount of precise, analytic rules and facts can capture the skill of an expert, but it is now possible for a computer to fly a helicopter *better* than an expert using only one hundred imprecise fuzzy rules and weighing them up through the logic of abduction.

Nursing expertise

Furthermore, by employing fuzzy logic, we can begin to elucidate Benner's formerly impenetrable concept of nursing expertise. As she rightly asserts, expertise requires a deep background understanding of the situation and a great deal of intuition. Dreyfus & Dreyfus, discussing the expertise of a doctor, argued that

> in reality, a patient is viewed by the experienced doctor as a unique case and treated on the basis of intuitively perceived similarity with situations previously encountered. That kind of wisdom, unfortunately, cannot be shared and thereby made the basis of a doctor's rational decision.
>
> (Dreyfus & Dreyfus 1986 p. 200)

However, fuzzy logic does precisely what Dreyfus & Dreyfus are saying cannot be done: it weighs up scientific facts and theories, previously encountered situations and personal knowledge of the individual patient and comes to a rational decision based on all of these diverse factors. Here is Kosko describing the working method of an expert judge

> The judge weighs up the principles and cites case precedents to back up the weights. The judge does not give the weights as numbers… but they are a matter of degree. Some weights rank more important than others. Some judges know more law and see more connections and cite more cases than others do. The judge cites these cases to justify her ruling. She does not point out an audit trail in a rule book. She gives what looks a lot like a fuzzy weighted average.
>
> (Kosko 1994 p. 180)

It seems likely that the expert nurse works in a similarly fuzzy way.

Case study

Fuzzy nursing is best illustrated with an example, and I shall return once more to the patient about to undergo surgery. I know that, in many cases, pre-operative information-giving can promote post-operative recovery and reduce pain (scientific theory), but I also know that there are exceptions to this general theory, and that anxious people often take *longer* to recover and suffer *greater* pain when given information. I suspect from my knowledge of previous cases (previously encountered situations) and from my developing relationship with this patient (personal knowledge) that he might not respond very well to being given pre-operative information. By abductive reasoning

> This patient is particularly anxious
>
> anxious patients, if given pre-operative information, often take longer to recover and experience more pain following surgery
>
> therefore I will only give this patient very minimal pre-operative information.

Thus, from my knowledge of the scientific theory that anxious patients do not respond well to pre-operative information, from consideration of past cases where I have or have not given information, and from my personal knowledge about the nature of this patient's personality, I can abduce that he should not be given very much pre-operative information.

As with Kosko's judge, the accuracy of my abduction will depend on how well I know this particular patient, that is, on my personal knowledge of this individual case, on the volume and diversity of my past experience and on how much scientific knowledge and theory I have at my disposal. Furthermore, I can, if necessary, explain how I came to my decision; I can not only state at least some of the fuzzy rules which I employed in deciding on my course of action, but I can roughly estimate the weight that I assigned to each of them.

The reason for articulating this process is not to dictate to experts how they *should* practice, but rather to attempt to illustrate how they already *do* practice. The strength of this model is therefore not in its prescriptive ability but in its descriptive ability; it provides the missing link in Benner's model by suggesting a tentative explanation of the intuitive process underpinning expertise. But more important, it allows the expert nurse to verbalise and justify her professional judgements and clinical decisions. The expert nurse is a fuzzy nurse and fuzzy nurses are able not only to do, but to explain how and why they do what they do.

CONCLUSION

Benner's model suggests that expertise is something that mysteriously develops over time largely outside the control of the nurse, who is at a loss to account for it. By examining expertise from the perspective of fuzzy logic and abductivism, however, it should be possible to help the expert practitioner to articulate how she arrives at her expert decisions, and even to begin to assign a weighting to each of the fuzzy rules she employs. And as we come to understand the logical processes involved, we might reach the point where expertise can not only be verbalised, but passed on from teacher to pupil.

Finally, let us return to Chuang Tzu's wheelwright, who could not put his expertise into words in order to teach it to his son and was therefore still making wheels at the age of seventy. Ironically, he had already made a start at verbalizing his art by stating a number of fuzzy rules: if you work too slowly, you can't make the wheel firm; if you work too fast, the spokes won't fit in; you must go neither too slowly nor too fast. If only he had lived two and a half thousand years later, he might have been able to pass on his expertise to his son and enjoy his retirement.

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