'Science', 'critical thinking' and 'competence' for *Tomorrow's Doctors*. A review of terms and concepts

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Context The recommendations of the General Medical Council in *Tomorrow's Doctors* renewed efforts to define core knowledge in undergraduate medical education. They also encouraged better use of the medical knowledge base in nurturing clinical judgement, critical thinking, and reflective practice. What then does the medical world understand by 'science', 'critical thinking' and 'competence', given the need to address both growth and uncertainty in the knowledge base and to practise evidence-based healthcare?

Aim and objectives This review aims to outline the role of these key concepts in preparing undergraduate medical students for professional practice. Specifically, it explores: the fallibility of the 'scientific' foundations of medical practice; the role of understanding and thinking in undergraduate medical education; the need for a broad interpretation of competence and its relationship to transferability, and the nature of clinical judgement.

Comment Tensions are seen to lie in the varying interpretations of clinical decision making as art or science; the varying characterizations of the nature of skilled performance in the novice, the competent and the expert practitioner, and the varying reactions to the acceptability and usefulness of 'meta-' concepts in capturing the essence of professional practice. Habitual self-conscious monitoring of mental processes may be the key to the flexible transfer and application of knowledge and skills across the contexts, characterized by uncertainty and incomplete evidence, for which doctors must be prepared.

Keywords Clinical competence; education, medical undergraduate, standards, methods.

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Introduction

British undergraduate medical curricula have long struggled to prevent factual overload from suppressing critical thinking.[1] The recommendations of the General Medical Council (GMC) in *Tomorrow's Doctors* renewed efforts to define core knowledge. They also encouraged better use of the medical knowledge base in nurturing clinical judgement, critical thinking, and reflective practice.[1] Some British undergraduate medical curricula (in Glasgow, Liverpool, and Manchester) have reformed comprehensively to the combined method and philosophy of problem-based learning (PBL). Problem-based learning promotes efficient knowledge acquisition and use via self-directed collection, critical appraisal, and synthesis of evidence (and active self-evaluation) according to learning objectives generated by students from facilitated small-group work on a clinical scenario.[2] Such approaches, which encourage large-scale curriculum development, place the scientific foundations of medicine under close scrutiny.[3]

What then does the medical world understand by 'science', 'critical thinking', and 'competence', given its need to address both growth and uncertainty in the knowledge base and to practise evidence-based healthcare? This review aims to outline the role of these key concepts in preparing undergraduate medical students for professional practice. Specifically, it explores:

- the fallibility of the 'scientific' foundations of medical practice;
- the role of understanding and thinking in undergraduate medical education;
- the need for a broad interpretation of competence and its relationship to transferability, and
- the nature of clinical judgement.

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Science and the 'truth' in medicine

> *…I have often seen barriers to communication and problem solving that at root are epistemologically based – that is, based on conflicting assumptions about the nature of knowledge and truth.*[4]

Science is revered in everyday life, the media, and academic and scholarly circles.[5] Medicine's relationship with science is supposedly transparent, axiomatic, and worth emulating by other healthcare professions. Anecdotally, however, medical students and doctors are often reminded that they are not 'real scientists', and the competition between basic science and clinical components of traditional undergraduate medical curricula reflects such tension. Nevertheless, doctors partly derive their professional status from custody of a knowledge base regarded as being founded on scientific methods.

Arguably, however, eager to verify its truth claims, medicine has unknowingly identified with some less than robust aspects of 'the scientific method', often failing to question its supposedly self-evident integrity. As new discoveries are incorporated into the knowledge base, the reality of uncertainty[6] is underplayed. Science is, however, essentially quixotic, defying all-encompassing definition. In the controversial field of the philosophy of science, Chalmers, for example, on critiquing and rejecting the exclusively rationalist and relativist accounts of science and scientific advance (Table 1), considered science to be an 'historically evolving body of knowledge'.[5] He criticized misconceived empirical notions of science and maintained that:

- no method can prove scientific theories to be true or probably true;
- no concept of truth is capable of defining science as a search for truth, and
- no single category called 'science' can be delimited.

This fallibility is generally ignored in the view of science that underpins traditional undergraduate medical curricula,[7,8] and staff are likely to gauge curricular innovation against the perceived scientific robustness of its content. Medicine is, however, essentially an applied science (or a scientific art?[8]), interpreting evidence and applying it to real-life, using critical thinking skills and experience. Fixed notions of the supremacy of the medical knowledge base in developing good clinicians therefore need to be challenged in the context of undergraduate medical education.

Understanding and skill

The educational recommendations in *Tomorrow's Doctors* envisaged better thinking and learning skills grounded in understanding. Barnett characterized higher education as unique amongst institutions in being charged by society with combining all six knowledge functions: transmission, understanding, application, storage, critical examination, and development of knowledge.[9] He described higher education as a meta-education to 'develop the emancipatory capacities'[9] for reading situations and applying appropriate skills.

Understanding is difficult to characterize. Hamilton described learning as a journey from learner readiness, through the 'intellectual upheaval' of assimilating experience, to arrive at understanding ('the capacity to reach beyond the realm of recipe knowledge').[10] Holt attributed understanding if ideas could be explained in different words, illustrated with examples, recognized elsewhere, connected with other ideas, used flexibly, and have their consequences and opposites identified.[11] Wolf noted that National Council for Vocational Qualifications (NCVQ) guidance refers consistently to 'knowledge and understanding', and that any disentangling of them is irrelevant.[12]

Table 1 A summary of critiques of rationalist and relativist accounts of science and scientific advance (after Chalmers[5])

Rationalist definitions, based on simple criteria

- Inductivism, in which truth lies in experience, and facts gleaned from observation allow laws and theories to be formulated (by induction) to predict and explain phenomena (with deductive reasoning logic). According to Chalmers, however, observation statements are fallible, generally being formulated using prior knowledge to interpret observations. Sophisticated inductivists accept that science cannot invariably start with observation.
- Falsificationism, in which a more 'do or die' approach holds. Problems are the starting point, and advances are made by learning from mistakes. Evidence is produced to falsify theories. New falsifiable theories are freely created to explain phenomenona and guide observations. They cannot be deemed true, only that they are better than previous versions.
- Lakatos' supposedly rationalist view of scientific advance (illustrated by physics), which focused on logical progress by systematic decisions of individual researchers or research groups.

Relativist definitions, in which no single absolute criterion defines science, for criteria change with individual and societal values

- The Kuhnian account of scientific advance, deemed to be relativist, distinguishing science from non-science by the existence of a paradigm, and by Kuhnian scientific revolutions occurring at crisis points in understanding, moving scientists from one paradigm to the next. This paradigm shift is not for some compelling logical reason but for a multitude of psychological and sociological reasons.

'Learning for understanding' has been pivotal in developing professional education. Machiavelli challenged 15th century philosophy by asserting that human affairs could be determined by human free will (and not merely by God and chance), thus implying that understanding should drive state officialdom.[10] Between the 15th and 19th centuries, such humanistic notions progressively underpinned, first, state officialdom and, latterly, professional practice.[10] Machiavellian ideas provided the self-regulation framework for professionals 'to harness… their powers of free will and understanding'.[10] Historically, learners destined 'to lead' needed understanding to manage the unexpected,[10] adapting technical knowledge to find creative solutions to new problems.

Turning to skill, this is usefully defined as an organized activity that is adaptable with feedback and can become routine.[13,14] In professional education, however, students must not merely learn routines. They must draw on their knowledge and understanding to apply skills flexibly in new and unfamiliar contexts:

> *…a higher education cannot be skills based. …skills will, at most, form part of the repertoire of capacities to be developed and which graduates will, with discrimination and care, deploy or not according to their reading of a situation.*[9]

In the field of artificial intelligence, computer scientists and mathematicians have long tried to model expert performance. In the Dreyfus model of skill acquisition (developed from studying chess players and pilots),[13] five levels link technical and intuitive aspects of expertise (as summarized by Benner[15] concerning nursing):

- Level I (novice): cannot use discretionary judgement and learns rules for action according to *specific* characteristics of a situation.
- Level II: (advanced beginner): can perform acceptably and, from prior experience, will notice recurrent, relevant, *general* characteristics of a situation, but needs support to prioritize.
- Level III: (competent): lacks speed and flexibility but analyses, prioritizes, and plans action, and assumes mastery and ability to cope with contingencies.
- Level IV: (proficient): perceives situations as wholes, not just aspects, is guided by situationally dependent maxims, and recognizes abnormality.
- Level V: (expert): only resorts to analytical tools, rules, and maxims in novel situations, and can see what is possible and what is not worth pursuing.

Developing expertise means moving from reliance on abstract principles to incorporating past experience, and from perceiving situations as comprising equally relevant pieces to seeing a whole in which only some pieces are relevant.

Benner warned against fractionating expert nursing performance because, in the Dreyfus model, progression is not about internalizing rules and formulae but abandoning them as practical experience provides paradigms. Benner recommended describing expert performance holistically, acknowledging experts' inability to articulate every critical step. By developing the concept of 'fuzzy logic', however, computer scientists have now got closer to describing and reproducing expert decision-making. Fuzzy problem-solving applies several rules simultaneously, not a linear chain of if–then algorithms, and applies a 'fuzzy weighted average'.[16] This 'abductive reasoning' resembles intuition, but can be described as rule-governed behaviour.

In principle, if the medical expert decision-making process can be described, educational intervention is possible. Nevertheless, abductive reasoning requires a deep understanding of the subject: both broad experience of similar instances and personal understanding of the particular presenting problem.[16] This challenges the clinical reasoning model, and its fundamentally hypothetico-deductive foundations, as presented by Barrows & Tamblyn (see below).[17]

Critical thinking and metacognition

The GMC wants medical students to be critical thinkers. According to De Bono[18] and others,[19] thinking is a skill and therefore 'teachable'. It is debatable whether the educational literature has neglected critical thinking, as claimed by Brookfield,[20] or been preoccupied with it, as claimed by De Bono.[18] This preoccupation was attributed to the ease of criticizing data that *exist*; to education's ecclesiastical origins, and to disregard of messy, generative thinking and scholarly thinking (passive, descriptive, contemplative).[18] Brookfield characterized critical thinking as 'a lived activity, not an abstract academic pastime',[20] a productive, positive, context-sensitive process, which is both emotive and rational and responds to both positive and negative events.

Halpern summarized the goals of critical thinking as:[21]

- to recognize propaganda;
- to analyse hidden assumptions in arguments;
- to recognize deliberate deception;
- to assess credibility of information, and
- to work through problems/decisions in the best way.

Halpern attributed to critical thinkers the characteristics of flexibility, persistence and a willingness to plan, self-correct, be aware of their own thought processes (metacognitive monitoring) and be consensus-seeking.[21]

Much self-knowledge is implicit in the concept of metacognition:

> *Until you 'KNOW WHAT YOU KNOW', you do not own your knowledge, and so you do not know anything.*[22]

If taken to imply more than 'knowing what you know', metacognition encompasses knowledge of how to learn best, of the strategic use of knowledge, and of personal factors influencing the effectiveness of learning and application. Crucial in problem solving,[23] metacognition is Nisbet & Shucksmith's 'seventh sense', bringing learning processes into consciousness.[24] Metacognition comprises higher level ('executive') monitoring and controlling of cognitive functions, linking decision making and memory, learning and motivation, and learning and cognitive development.[25] Such functions complement Brookfield's components of critical thinking: identifying and challenging assumptions and context, imagining and exploring alternatives, and exhibiting reflective scepticism.[20] Metacognitive monitoring includes 'ease-of-learning judgements', 'judgements of learning', 'feeling-of-knowing judgements', and 'confidence in retrieved answers',[25] providing the personal insight (albeit with occasional intellectual discomfort) needed to adapt skills to novel situations:

> *The good student may be one who often says that he does not understand, simply because he keeps a constant check on his understanding.*[11]

The *Tomorrow's Doctors* vision of a competent practitioner with a wider 'world-view' includes realistic notions of scientific evidence guarded by reflective scepticism, and this requires metacognition.

Competence and metacompetence

What lessons have competency-based approaches,[26] as exemplified by National Vocational Qualifications (NVQs), for university production of 'competent' doctors? Competence is about meeting a standard, a controversial concept at the core of the GMC's regulatory role. Competency-based approaches highlight how prescribed learning outcomes will be assessed, and hence learning needs.

Nevertheless, in higher education there is criticism of the competence movement for allegedly divorcing skills from the knowledge required to adapt them to unpredictable situations, and the movement's relevance and non-university origins in routine practical work are questioned.[27]

Arguing that competence-based approaches merit consideration similar to that of other educational approaches, Wolf made several points:[12]

- Competence is a construct involving performance to a given standard, e.g. set by the employer.
- The *process* of defining standards differs between occupationally based and non-occupationally based activities, not competence itself. This is usually because, for the former: 'the utilitarian justification for developing a competence is direct and obvious'[12] (e.g. for medical compared with philosophy graduates).
- Defining competence as synonymous with skill alone perpetuates a limited view focused merely on specific practical activities. Competence can be inferred via outputs, i.e. behaviour, or less directly via inputs, i.e. knowledge and understanding, and skills. Preferably, evidence should be accrued about both (to provide breadth and context). A separate assessment of 'knowledge and understanding' is necessary when occupations, like medicine, involve unpredictable and/or numerous diverse situations.

The main assessment challenge for university competence-based approaches[27] is therefore to make 'safe' inferences from knowledge when competence cannot realistically be assessed in all potentially relevant situations.[28]

Higher education curricula were not founded, however, on clear concepts of competence, and standard setting in professional education is generally difficult, for the following reasons.[9]

- The standard is highly debatable and needs to reflect public opinion because good medical practice, for example, is 'contested goods'.
- The standard cannot be divorced from process, as if only the outcome were relevant.
- It cannot easily reflect the graduates' need to respond to *and* shape a changing world.

Barnett argued that pushing higher education towards the vocabulary of competence merely replaces one closed ideological view of higher education, i.e. academic competence serving cognitive culture, with another, i.e. one-dimensional operational competence serving the economy:[9]

> *Whether in the vocabulary of competence, outcomes, skills and transferability (the new) or of intellect, knowledge, truth, objectivity and disciplines (the old), we are faced with limiting ideologies.*[9]

Although criticizing NCVQ-type competence, Hodkinson identified potential lessons for professional education:[29]

- making professional practice more transparent;
- deconstructing a daunting role for novices;
- clarifying expertise, by distinguishing functional levels, and
- facilitating holistic assessment.

Professionalism is potentially challenged, however, if such work is deskilled and 'proletarianized', by being deconstructed into a series of specialized but routine tasks.[30,31]

Fleming attributed academic unease with competence-based approaches to the linking role of metacompetence having been missed:[27]

> *Developing metacompetence is about lining subject-specific knowledge with the particular competences that should be practised by the learner.*[27]

Higher education fosters, however unknowingly, this higher order competence, which develops, selects, and adapts other competences for different situations, and facilitates change. Indeed, education with flexibility, critical insight, and potential for change underpinned the medieval disputation, when advanced university students justified their theses to selected opponents in official readings.[27] Blending knowledge, performance, and occupation illustrates metacompetence.

The self-understanding essential to metacognition resurfaces in this closely related concept. Metacognition's distinct contribution is towards learning to learn and transferring learning to new contexts, by bringing the process to conscious level.[24] Fleming distinguished between knowledge:[27]

- being for its own sake;
- genuinely underpinning competence;
- allowing competence to extend beyond situations in which it can realistically be assessed, and
- allowing competence to 'understand itself',[27] i.e. informing metacompetence.

Hyland criticized this subcompartmentalization, however, doubting that any knowledge could exist for its own sake alone, and preferring the concept of vocational or occupational expertise over metacompetence.[32]

The GMC explicitly wants competent graduates, flexible in thought and action, but is not explicitly advocating competency-based approaches *per se*. If competence-based approaches do not highlight 'knowing about knowing', however, concerns about their being ill-equipped for shaping and responding to change[9] are valid.

Clinical judgement, technical rationality and problem-solving

How does this all relate to clinical practice? Undergraduate medical education must foster clinical judgement, but widespread uncertainty bedevils key points in decision making:[33]

- defining the disease;
- diagnosing the disease;
- assessing potential outcomes of interventions in particular patients with differing preferences, and
- deciding on clinical management based on such information.

In accommodating such uncertainty, clinical decision making can be variously conceptualized. Eddy considered that doctors should acknowledge the vagaries of clinical decision making, and manage uncertainty scientifically using relatively neglected disciplines, such as statistics, economics, and decision theory[33] (to which should be added epidemiology).

Barrows & Tamblyn denied that the core medical task is primarily about solving problems; rather it involves managing insoluble problems.[17] They characterized clinical reasoning as being the cognitive process underlying clinical practice, usually referred to as problem solving (but sometimes as medical enquiry, clinical judgement, and diagnostic reasoning). Barrows & Tamblyn considered that doctors display dangerously inaccurate personal introspection when trying to appear scientific in explaining their practices to students. Their decision making is not as they perceive it to be:

> *To rearrange your cognitive steps to fit the acceptable medical 'norm' is not unlike tidying up the house for company so that they will think you are a good housekeeper.*[17]

Nevertheless, Barrows & Tamblyn promoted the scientific method, summarizing the hypothetico-deductive model of medical problem solving as:

- information perception and interpretation (selecting cues and forming the 'initial concept');
- hypothesis generation (of 2–5 hypotheses);
- enquiry strategy and clinical skills (a 'search and scan' approach to data collection);
- problem formulation, and
- closure via diagnostic and/or therapeutic decision making.

The model was criticized,[34] even by Elstein,[35] whose empirical work[36,37] was central to its development. The main messages,[2] from subsequent empirical evidence about clinical problem solving, are first that novices (and experts outside their field of expertise or in complex scenarios) use the laborious approach of hypothetico-deduction, by reasoning backwards from a hypothesized diagnosis to expected data that may or may not falsify it. Secondly, in familiar territory, clinical experts reason forwards from data to diagnosis, locating their relevant knowledge via pattern recognition with previous instances. Clinical experts also mix forward and backward reasoning, as required. Their problem solving surpasses that of novices by generating multiple, better hypotheses; using better knowledge-retrieval processes, organizing data around scientific principles, and incorporating experience.

Furthermore, Barrows & Tamblyn apparently held somewhat contradictory positions. They highlighted the difficulty with '[giving] the impression that what the physician does is an art, is intuitive, is not directly teachable, and can occur only with experience'.[17] They also pointed out that, under pressure in real clinical practice, a doctor must abandon the 'detailed, comprehensive workups he was taught in his formal education…[in favour of]…more time-efficient cognitive processes…'.[17] The issue of medicine as art or science therefore resurfaces:

> *Are the manifold uncertainties of contemporary clinical practice to be seen as the legitimate basis for regarding clinical judgment and decision making as significantly – even 'essentially' – artistic in character? Albeit, of course, an* art *that uses, and gains credibility from, the knowledge produced by the medical and other* sciences. *Or are claims to artistry just the way the profession dresses up its refusal to apply the same scientific approach to its own cognitive processes and behaviour that it insists upon in relation to processes and knowledge at the levels of organ and cell?*[38]

Barnett noted that 'scientism' (a modernistic perspective[8]) prevents recognition of tacit knowledge integral to professional practice.[9] Likewise, Schön disliked modelling professional clinical practice on a dubious interpretation of scientific method.[39–41] He criticized the dominance of a positivistic epistemology that he termed 'technical rationality', in which professional knowledge is considered to be specialized, circumscribed, scientific, and stereotyped for problem solving.[39] General principles occupy the top of the knowledge hierarchy, and problem solving the bottom.

> *The difficulty is that the problems of the high ground, however great their technical interest, are often relatively unimportant to clients or to the larger society, while in the swamp are the problems of greatest human concern.*[39]

Interestingly, the public health (population) perspective has been undervalued in medicine generally; this was echoed by the recommendation in *Tomorrow's Doctors* that public health education for medical students should be strengthened.[1] Public health doctors are probably inhabitants of Schön's 'swampy lowlands', because population-relevant problems potentially challenge conventional notions of science.

Schön favoured the intuitive craft-like aspects of clinical decision making (also acknowledged by Barrows & Tamblyn), i.e. 'knowledge-*in*-action' and 'reflection-*in*-action' rather than *for* action.[39] Surprise is pivotal in reflection-in-action, and arises when intuitive performance accommodates uncertainty:

> *The dilemma of rigor or relevance may be dissolved if we can develop an epistemology of practice… [that] …places technical problem solving within a broader context of reflective inquiry, shows how reflection-in-action may be rigorous in its own right, and links the art of practice in uncertainty and uniqueness to the scientist's art of research.'*[39]

Schön's 'professional artistry' looks very much like 'expert' performance in the Dreyfus model of skill acquisition. Surely *initial* professional education is intended, however, to produce the competent rather than the expert practitioner? It may well be possible to model the 'expert' process using fuzzy logic, yet it still appears to be founded on a greater library of experiences than the newly qualified professional can be expected to have. The competent practitioner is dependent on explicit analysis, prioritization, and planning – it could not be otherwise. It seems eminently reasonable to represent this process using the hypothetico-deductive model, as did Barrows & Tamblyn, yet this arguably misrepresents the expert clinical reasoning process. This is a challenging transition for medical (and much other professional) education, which needs to be addressed in postgraduate education and continuing professional development.

Increasingly, curricular reform involves the earlier introduction of clinical context and contact, and better integration of clinical and basic sciences. This challenges the traditional assumption of the 'preclinical–clinical divide', i.e. that 'theory' must precede 'practice'. Furthermore, those curricula that are comprehensively being transformed to problem-based learning start with the practical clinical application and context (in case scenarios) in order to generate learning objectives that often blur subject and preclinical–clinical boundaries.[2] Problem-based learning should maximize a store of experience and examples within the time available for undergraduate medical education, providing a basis for developing reflective enquiry.

Comment

The pre-eminent scientific foundations of medicine underpinning medical education can be challenged. One challenge is a clearer understanding of the nature of science and its strengths and limitations. Another is the recognition of the importance of something other than command of the knowledge base in applying clinical judgement, whether it is called professional artistry or expert performance. Moving through the hierarchy of skills acquisition from novice to expert requires experience. Any reasoning model must quite properly replace the rules guiding novice education with different sets as experience grows.

Furthermore, *Tomorrow's Doctors* recognized that medical students must be prepared to cope with the uncertainty and evolving understanding inherent in medical practice. For evidence-based practice, doctors must use critical thinking skills to appraise evidence. Thinking skills can probably be improved, but tomorrow's doctors also need to learn how to learn and know about knowing. Both metacognition and metacompetence are concepts that attempt to capture the essence of adapting to change and uncertainty. Doctors' self-understanding and insight into the nature and limitations of their knowledge, and their capacity to apply it are crucial.

References

1 General Medical Council. *Tomorrow's Doctors: Recommendations on Undergraduate Medical Education.* London: General Medical Council, 1993.
2 Maudsley G. Do we all mean the same thing by 'problem-based learning'? A review of the concepts and a formulation of the ground-rules. *Acad Med* 1999;**74**(2):78–85.
3 Maudsley G. Tutors' conceptualizations of problem-based learning in an undergraduate medical curriculum. Master of Education Dissertation. Liverpool: The University of Liverpool, 1997.
4 Kolb DA. *Experiential Learning: Experience As The Source Of Learning And Development*. Englewood Cliffs, New Jersey: Prentice Hall, 1984.
5 Chalmers AF. *What Is This Thing Called Science?* 2nd edn. Buckingham: Open University Press, 1982.
6 The Lancet. The science of making mistakes [editorial]. *Lancet* 1995;**345**:871–2.
7 Margetson D. Current educational reform and the significance of problem-based learning. *Studies Higher Educ* 1994;**19**(1):5–19.
8 Leggett JM. Medical scientism: good practice or fatal error? *J R Soc Med* 1997;**90**:97–101.
9 Barnett R. *The Limits of Competence: Knowledge, Higher Education and Society.* Buckingham: The Society for Research into Higher Education, 1994.
10 Hamilton D. *Learning About Education: an Unfinished Curriculum.* (Series: Innovations in Education.) Buckingham: Open University Press, 1990.
11 Holt J. *How children fail.* 2nd edn. London: Penguin, 1982.
12 Wolf A. Can competence and knowledge mix?. In: JW Burke, ed. *Competency-Based Education and Training.* London: Falmer Press, 1989: pp 39–53.
13 Dreyfus HL, Dreyfus SE. Putting computers in their proper place: analysis versus intuition in the classroom. In: D Sloan, ed. *The Computer in Education: a Critical Perspective.* Columbia, New York: Teachers, College Press, 1984: pp 40–63.
14 Eraut M. Initial teacher training and the NCVQ model. In: JW Burke, ed. *Competency-Based Education and Training.* London: Falmer Press, 1989: pp 171–185.
15 Benner P. From novice to expert. *Am J Nurs* 1982;**82**(3):402–7.
16 Rolfe G. Science, abduction and the fuzzy nurse: an exploration of expertise. *J Adv Nurs* 1997;**25**:1070–5.
17 Barrows HS, Tamblyn RM. *Problem-Based Learning: An Approach to Medical Education.* [Series: Medical Education, vol. 1.] New York: Springer, 1980.
18 De Bono E. *Teaching Thinking*. Harmondsworth: Pelican Books, 1978.
19 Blagg N, Ballinger M, Gardner R. *Somerset Thinking Skills Course: Handbook*. Oxford: Basil Blackwell/Somerset County Council, 1988.
20 Brookfield SD. *Developing Critical Thinkers: Challenging Adults to Explore Alternative Ways of Thinking and Acting*. Milton Keynes: Open University Press, 1987.
21 Halpern DF. *Thought and Knowledge: an Introduction to Critical Thinking*. 3rd edn. Mahwah, New Jersey: Lawrence Erlbaum Associates, 1996.
22 Horwitz L. Learner autonomy: a case study. In: SW Weil, I McGill, eds. *Making Sense of Experiential Learning: Diversity in Theory and Practice.* Milton Keynes: The Society for Research into Higher Education/Open University Press, 1989: pp 81–6.
23 Davidson JE, Deuser R, Sternberg RJ. The role of metacognition in problem solving. In: J Metcalfe, AP Shimamura, eds. *Metacognition: Knowing About Knowing.* London: Massachusetts Institute of Technology Press, 1994: pp 207–26.
24 Nisbet J, Shucksmith J. *The Seventh Sense: Reflections on Learning to Learn.* Edinburgh: Scottish Council for Research in Education, 1984.
25 Nelson TO, Narens L. Why investigate metacognition?. In: J Metcalfe, AP Shimamura, eds. *Metacognition: Knowing About Knowing.* London: Massachusetts Institute of Technology Press, 1994: pp 1–25.
26 Challis M, Usherwood T, Joelsbury H. Assessing specified competences in medical undergraduate training. *Competence Assessment* 1993;(22):6–9.
27 Fleming D. The concept of meta-competence. *Competence Assessment* 1991;**16**:9–12.
28 Mitchell L. The identification of knowledge. *Competence Assessment* 1989;(7):4–6.
29 Hodkinson P. Professionalism and competence. In: P Hodkinson, M Issitt, eds. *The Challenge of Competence: Professionalism Through Vocational Education and Training.* London: Cassell, 1995: pp 58–69.

30 Blane D. Health professions. In: DL Patrick, G Scambler, eds. *Sociology as Applied to Medicine,* 2nd edn. London: Baillère Tindall, 1986: pp 213–20.
31 Ellis R. Competence in the caring professions. In: R Ellis, ed. *Professional Competence and Quality Assurance in the Caring Professions.* London: Chapman and Hall, 1988: pp 43–57.
32 Hyland T. Meta-competence, metaphysics and vocational expertise. *Competence Assessment* 1993;(20):22–4.
33 Eddy DM. Variations in physician practice: the role of uncertainty. In: J Dowie, A Elstein, eds. *Professional Judgment: A Reader in Clinical Decision Making.* Cambridge: Cambridge University Press, 1988: pp 45–59.
34 Norman GR, Trott AD, Brooks LR, Smith EKM. Cognitive differences in clinical reasoning related to postgraduate training. *Teaching Learning Med* 1994;**6** (2):114–20.
35 Elstein AS. What goes around comes around: return of the hypothetico-deductive strategy. *Teaching Learning Med* 1994;**6** (2):121–3.
36 Elstein AS, Kagan N, Shulman LS, Jason H, Loupe MJ. Methods and theory in the study of medical inquiry. *J Med Educ* 1972;**47**:86–92.
37 Elstein AS, Shulman LS, Sprafka SA. *Medical Problem Solving: An Analysis of Clinical Reasoning.* Cambridge, Massachusetts: Harvard University Press, 1978. [Cited in Elstein AS, ref. 35]
38 Dowie J, Elstein A. Introduction. In: J Dowie, A Elstein, eds. *Professional Judgment: A Reader in Clinical Decision Making.* Cambridge: Cambridge University Press, 1988: pp 1–41.
39 Schön DA. From technical rationality to reflection-in-action. In: J Dowie, A Elstein, eds. *Professional Judgment: A Reader in Clinical Decision Making.* Cambridge: Cambridge University Press, 1988: pp 60–77.
40 Schön DA. *The Reflective Practitioner. How Professionals Think in Action.* Aldershot: Ashgate Arena, 1983 (rev. 1991).
41 Schön DA. *Educating the Reflective Practitioner.* San Francisco: Jossey Bass, 1987.

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