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Distributed and relative nature of professional expertise

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This exploratory study investigates the distributed nature and complexity of professional expertise by examining the patterns of cognitive processes in novices and experts who are using ultrasound technology to make diagnoses. The study aims to identify and provide an explanation for such patterns in light of the recent debate on the locus of control underpinning human cognition. A distributed model of professional expertise based on the relationships between the four elements of socio-cultural disposition, tools and artefacts, strategies, and domain knowledge, is used to discuss the results. The findings illustrate the complexity of professional expertise, particularly when individuals depend on sophisticated tools to assist their thinking and reasoning.

Introduction

This is a study of the cognitive processes used by novice and expert professionals in carrying out a workplace activity, namely how professional experts (veterinarians) draw upon their professional knowledge and skills when making diagnoses using ultrasound images. Such an investigation initially requires a definition of professional expertise and a consideration of the appropriate explanation of how learning occurs in such a context.

First, a definition of professional expertise: professional expertise develops within a given domain of knowledge only as a result of contextualized training and practice (Ericsson & Smith, 1991). It can be defined as the ability to combine domain knowledge with appropriate professional tools and strategies to solve problems within the socio-cultural context of the profession. With increasing expertise, the individual is able to bring sufficient knowledge and experience to deal with more complex and novel situations. Thus, when presented with an uncommon set of symptoms, an expert is more effective in drawing upon the complex set of factors noted above and diagnoses successfully, while a novice would struggle.

However, it should be noted that the notion of expertise is very domain specific and this is readily demonstrated once an expert is taken out of their specific domain, even within the broader field of their profession. It is also relative, in the sense that a novice may be a recently graduated university student with expertise in domain knowledge. Such a student is different from those who do not have any knowledge of the domain area but also may be classified as novices. Thus, it is important to recognize the progressive developmental aspect in what constitutes expertise; at any one point in time an individual can be at a different level on the expertise continuum.

Second, a consideration of context-based learning: most contemporary learning theories have been strongly influenced by models derived from the individually focused discipline of psychology. However, as we learn more about human learning and the competencies required for a contingent and dynamic workplace, alternative models of human learning are emerging. Ve´rillon and Rabardel (1995) argue that whilst psychology has furthered our general understanding of individual cognitive processes and that there are coherent models that are satisfactory and can be adopted, it is insufficient to explain the socio-cultural aspect of human learning and explain pragmatic action manifested in this study as professional expertise. Amongst the significant emerging learning theories are situated cognition and, more recently, the distributed cognition model of human learning and performance (see Salomon, 1993). While the situated cognition proponents contributed to relocating the locus of learning agency from the individual to the context and culture of a professional practice, it is still viewed as a single position rather than accommodating it as an expansion of our understanding of the varied and legitimate views of learning (see Billett, 2002). Alternatively, distributed learning models propose an interaction model in which individuals connect with a number of different cognitive systems, such as the individual's mind, the context (including cultural values and dispositions), the strategies, and the artefacts or tools (Pillay & Elliott, 2001). They emphasize that knowledge underpinning expert behaviour does not reside in any one cognitive system; rather, it is in the interactive relationship among these cognitive systems. We argue that this interaction between various cognitive systems could be viewed in a similar vein to Altman (1988), who states that it is nonsensical to conceive of learner interaction as unidirectional or linear, thus challenging the implied directionality that can be found in many learning models.

Furthermore, the interactions could be viewed as reflexive or co-constructed, similar to what Bandura classifies as continuous ‘reciprocal determinism’ which is an interactive meaning-making process between an individual’s behaviour, cognition and environmental influences (Bandura, 1997). For example, Bolter (1984) argues that while human memory shaped the design of technologies and cultural tools, it is also reciprocally influenced by them: computers were constructed by humans, now they influence how humans live, think and work. This challenges the traditional notions of learning processes and environments, and the types of interactions possible within workplace environments. Our thesis is that there is a need to explore reciprocal determinism, and synchronous and asynchronous interaction, as a basis for learning in general and in particular for developing professional expertise. We see human cognition as an interactive process where the meaning lies in the interaction rather than in the activity that facilitates the interaction. These notions are explored in more detail below.

There is an increasing acknowledgment of the complexity of competencies required of people to be effectively functioning in today’s workplaces (e.g. Hesketh, 2000; Pont & Werquin, 2001; Stasz, 2001; Pappada`, 2003). This complexity, embedded in the socio-cultural context, strongly suggests that knowledge and skills that may constitute professional expertise are distributed in nature. The constructivist may argue that all meaning is constructed by individuals where the locus of control for this process is located with the individual. However, Bandura’s (1997) reciprocal determinism seems to suggest that there is ‘reciprocal influence’, both from the individual and socially constructed norms and meanings that govern a cultural context which assist in deriving the final meaning and understanding.We believe that this reciprocity and interdependence of individual and the context, in personal meaning making and professional judgements, is central to expert reasoning processes. Individuals interpret the inherent aspects in tools, symbols, forms, ideologies, rules, assumptions found in a socio-cultural context, but for these aspects to exist in that socio-cultural context there must be a reason and purpose which may not be individually constructed but socially determined.

On the basis of a detailed review and synthesis of recent literature in learning and particularly workplace learning (e.g. Beckett & Hager, 2000, 2002; Fenwick, 2001) we propose an interactive model of professional expertise that involves four broad factors: cultural dispositions; tools/artefacts; substantive content knowledge; and strategies. This model is summarized in Figure 1.

Figure 1 is presented as (1a) and (1b) to ensure that all possible combinations of interactions are covered. The position of the factors in (1a) captures only eight possible combinations of interactions; thus by sliding the factors around, the additional three can be illustrated, as seen in (1b). The model assumes the four factors to be in a fluid state so they can slide around to capture all 11 combinations of interactions as necessary. These 11 possible combinations of interactions between

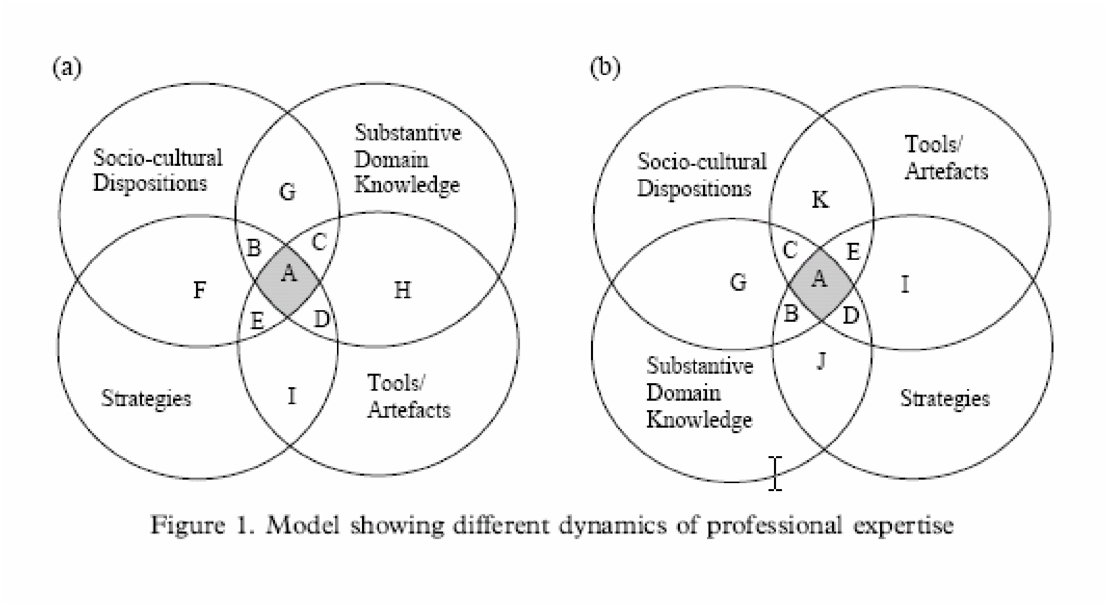

Figure 1. Model showing different dynamics of professional expertise

the four factors are labelled A, B, C . . . K. These are shown as overlap of the circles in Figure 1, parts (1a) and (1b). The interactions between the four factors may occur differently, thus locations in Figure 1 are indicative only to represent the combinations of interactions.

The section marked A is the ideal, with a blending of all factors, but due to its complexity it may be accessible to only a small number of professionals. Other sections such as B, C, D and E are also legitimate representations of professional expertise, and may be appropriate for tasks of different levels of complexity. Thus, expertise appears to be relative to the task in hand. It is unrealistic to expect everyone to be in the A category, and in fact being in this category may not be necessary all the time for expert performance. According to our model, the meaning-making process that underpins professional expertise is not singularly located at any of the four nodes; rather, it is in the interaction between them. This would suggest that it has to be created, based on available information in a synchronous and asynchronous manner. Since the four factors presented in Figure 1 are very different from previously conceived elements of professional expertise, the significance of these factors is discussed.

Socio-cultural aspects that may affect individuals' dispositions and values

Cole and Engestro¨m (1993) argue that culture is a patterned ensemble of beliefs, values, symbols and tools and is considered uniform as it is experienced at a local level with local interaction and values. This is similar to workplace cultures that underpin professional practices. Thus, the socio-cultural knowledge and skills in a profession are particularly important as they can have significant influence on the day-to-day behaviour and performance of professionals. For instance, recently some medicine degree courses in Australia have introduced communication and people skills as part of the professional medicine degree, because being a professional medical practitioner is now viewed as requiring more than the domain-specific medical knowledge. This addition has added a new competency for medical practitioners such as 'effectively communicating with patients', thereby acknowledging the significance of socio-cultural values and expectations. The above assumes a degree of stability in what constitutes 'professional cultures', thereby allowing patterns to develop and be recognized.

However, Schwartz (1990), analysing the American culture, views culture as being distributed across people, generations, religions, occupations, social classes, and so on, and the meaning of a culture arises from a distributed phylogenetic structure. Similar propositions can be seen in Geertz's (1973) and Valsiner's (2000) conceptual argument on the nature of cultures. It is assumed to be evolving, and thus the social distribution of cognition continuously adds to and subtracts from the degree of common culture. This contingent and dynamic nature of culture presents challenges to the linear, stepwise professional development initiatives. Unless one appreciates the complex and multitudinous nature of variables and their interactions, the significant influence of cultural dispositions, 'power distance' (the subservient behaviours expected of subordinate staff in certain cultures), and ideologies may not be realized, and consequently the full potential of professional expertise may not be appreciated.

Another perspective to this cultural dimension of professional expertise is in understanding the background to problems. Often the case history of problems can be steeply entrenched in cultural biases and an interpretation that takes these into account reflects a significant aspect of professional expertise. Therefore, professional expertise can be a very cultural and ideologically driven activity, and individuals need to continuously position themselves within this socio-cultural aspect of developing specific professional expertise and the associated knowledge and skills.

Substantive domain-specific knowledge and skills

The second factor in our model of professional expertise is the role of substantive content knowledge. Learning and developing critical insight in any subject domain involves extensive understanding of the content knowledge. This constitutes more than the rules, facts and theories. Spiro and Jehng (1990) argue that to comprehend the nature and scope of variability of a concept within a domain an understanding of the structural and functional aspects of domain knowledge is required. Functional aspects refer to the content, while structural aspects refer to the format and the logic of thinking evident in problem types of respective subject disciplines. As all substantive content knowledge has its own structure, symbols, and representations, an understanding of that structure can assist in recognizing functional aspects, which in turn can shape the strategies chosen by individuals to make sense of the given information. In recent years, the emphasis on processes (strategies focusing mainly on procedural knowledge) as being central to facilitating learning has unintentionally downplayed the significance of domain knowledge. A deep understanding of the domain knowledge privies one to punctuate the structural and functional aspects of domain knowledge with appropriate strategies (methods that allow individuals to access, record and analyse non-transparent information regarding relationships between domain knowledge and context, strategies, and so on) so that optimum learning and performance occurs. Similarly, functional and structural understandings of domain knowledge allow professionals to draw on finer aspects of the domain knowledge when making professional judgements about given situations. Thus, professional expertise may be influenced significantly by one's level of understanding of the domain knowledge.

Further support for the multilevel nature of professional knowledge can be seen in the diversity of professional experts required in an area underpinned by common discipline knowledge, and how fragile their expertise is when they are removed from their specific domain. This is further confounded by the blurring of boundaries between traditional domains where, in some cases, the search for breadth at the expense of depth of domain knowledge is causing much tension in understanding the significance of domain knowledge in fostering professional expertise. It is also important to note that often individuals classified as novices in professional expertise may still be experts in domain knowledge.

Strategies to enhance human learning and professional capacities

The third factor in our model that is significant in developing professional expertise is strategies for learning and performing the tasks in professional practices. Strategies reorganize our thinking processes by providing effective heuristics and models to follow, both for general purposes as well as those focused on particular domains (Perkins & Grotzer, 1997). While strategies have commonly been used to learn and perform routine physical tasks, in recent years the increasing recognition of a need for professional competency in reasoning and explanation is changing the nature of strategies used by experts. Even routine procedures now require experts to demonstrate a certain level of interpretative and explanative capacities. There are different strategies for developing different types of professional knowledge and skills, each of which can be enhanced through practice and progressive appropriation to fit the tasks in hand (see Billet, 1999). Sometimes the strategies are used in a very simplistic manner, such as following a series of steps. Strategies are more powerful when the practitioners appreciate the theoretical and ideological underpinnings and assumptions behind them; however, some strategies may not be appreciated in certain cultures. Consistent with the interactive nature of the distributed model, it should be recognized that strategies are influenced by the context (including culture) and substantive domain knowledge, just as the content and context are influenced by the chosen strategies. For instance, a strategy such as mentoring has been in existence for centuries, but as we try to formalize it we often do not fully appreciate the impact of political (including industrial relations) and cultural ideologies in expecting fellow workers to share their expertise (intellectual property). Also, the effectiveness of mentoring is in its informal and self-selecting nature which may not be the same when it is formalized and empowered through labour legislations.

Artefacts to support professional competence

The fourth factor in our model is the role of artefacts (or tools) used in professional practice and seen in workplaces and learning environments. They can significantly assist reasoning, diagnostic capacity, and meaning-making processes and enhance the facilitation of professional expertise. The reliance on tools for diagnosing and assisting everyday work activities is increasingly becoming a norm rather than an exception. Whilst such equipment is capable of providing information about the condition of systems under investigation, individuals still need to make sense of the graphical or other types of output generated by those tools to develop in-depth understanding and interpretations of the problems in hand. Cole (1996) refers to tools as both material and conceptual artefacts that people use to extend their own capacities. Tools can be both intangible (such as language conventions) and tangible (such as computer systems). Societies, cultures and even strategies can be shaped to a large extent by the artefacts of that society. Norman (1991) suggests that tools may form part of an environment but they are distinct and more than just a fixture within the environment.

Artefacts have an epistemology of their own and thus influence our meaningmaking process. For instance, Ve´rillon and Rabardel (1995) asked students to imagine the transformation of a block of wood into different shapes and found that tools that caused transformation influenced their imaginations. Removing material was conceived as sawing, thus the thinking was constrained by the capability of a saw. We invent tools such as medical diagnostic equipment, which in turn shape our thinking as we begin to see through the ‘eyes’ of this equipment, thus our cognition is constrained and sometimes enhanced by such tools. Furthermore, many strategies adopted by experts are often shaped by the inherent capacities of the tools and vice versa, with little or no reference to human factors.

Reconceptualizing the nature of professional expertise

Having considered the above four factors as a way to conceptualize professional expertise, our proposed model posits that professional expertise and meaning making involve a dynamic interaction between these four factors. Despite the current trend of focusing on narrow education and training interventions involving a single factor, it must be noted that none of the four factors is sufficient on its own to promote professional expertise. The need to consider all aspects of a concept can be seen in the social construction of meaning (Vygotsky, 1978) and distributed cognition learning models (Pea, 1993). These authors argue that meaning is not located in the collective composition of a concept; rather, it involves an understanding of the elements which constitute the concept and their interaction which makes the collective meaning. In considering the complex nature of human activities, Leont'ev (1981) called it the human activity system, which was seen as the basic unit of analysis of human behaviour. Expanding on this work, Cole and Engestro¨m (1993, p. 8) argued that 'activity systems are best viewed as complex formations in which equilibrium is an exception, and tensions, disturbances and local innovations are the rule' and the engine for learning and transformation.

Thus, against the above discussion, any understanding of professional expertise requires a full understanding of the elements of which it is constituted and the dynamic interaction of those elements. We propose a four-factor model (see Figure 1) that builds on previous separate studies of these four individual factors, namely the socio-cultural dispositions, strategies, domain knowledge and the tools and artefacts of a profession. Expert professional practitioners constantly need to negotiate between these four factors to make professional judgements. The model also emphasizes the relative and highly narrow nature of professional expertise. These assertions are investigated in the following study.

The study

Background to the study

The study reported here intends to identify and illustrate patterns of how professional experts (veterinarians) draw upon their professional knowledge and skills when making diagnoses using ultrasound images. Ultrasound technology was used to understand the role of tools in shaping professional expertise. Professional ultrasonographers engage in reasoning and interpretations of ultrasound displays which include dispositions and cultural biases, strategies, domain knowledge and awareness of the tools. They make inferences not only through deductive and inductive reasoning but also visual reasoning. When dealing with visual reasoning in graphical images displayed by electronic diagnostic equipment, individuals draw upon previous knowledge and experiences (including cultural values) to make inferences and proceed from a primitive description to complex understanding about the implied and explicit knowledge (Pillay et al ., 2001).

Presumably, initially, we rely on general heuristic processes, and subsequently, after verification, we develop powerful and reliable strategies to make inferences (similar to those used by experts). We posit that the construction and use of these inferences and strategies, supported by domain knowledge and cultural values, facilitate the development of professional expertise.

An approach to understanding the above is through characterizing and ordering the synchronous and asynchronous relationships between the domain knowledge, the strategies, the tools and the cultural dispositions adopted by professional experts on specific tasks. Tools such as ultrasound technology are often based on a referential framework to display spatial information. Winn (1993) argues that such graphical information consists of symbols, which have 'emergent properties' such as basic form/shape, texture and colour, a concept which is similar to Treisman's (1988) feature identification. This use of emergent properties can be both beneficial and also a hindrance to accessing information by influencing the ability to discriminate. Making judgements to discriminate these properties involves a level of risk. In some cultures, taking risks is not encouraged because it can have an adverse effect such as 'loss of face' by the expert*/thus it can limit an expert's repertoire of possible procedures. On the other hand, extensive experience in dealing with a range of emergent properties would facilitate development of typical task knowledge that can be useful in dealing with subsequent exposure to other related graphical information. Against the above backdrop of the discussion on both the distributed model for professional expertise and working with graphical displays as found in ultrasound technology, this study intends to investigate the patterns and nature of relationships between socio-cultural dispositions, substantive domain knowledge, and strategies for a group of experts working with ultrasound tools.

Method

Design. Previous research on human reasoning and explanation has demonstrated that protocol analysis provides a powerful tool for studying cognitive processes such as reasoning and explanation that underpin professional expertise (Anzai, 1987; Chi et al ., 1989; Koedinger & Anderson, 1995). The explanation paradigm has received increasing attention in cognitive science and educational research (Chi et al ., 1989; Patel & Groen, 1991). While problem solving provides appropriate methods for investigating the development of procedural knowledge and strategies, explanations and reasoning are more appropriate for investigating and drawing inferences about the conceptual structure and decision making which differentiate professional experts from amateurs. Explanation and reasoning have the added advantage of being naturally expressed in a verbal manner, which has been found to be more fluid and coherent (Kaufman & Patel, 1991).

A rigorous model for cognitive task analysis is the Precursor, Action, Results and Interpretations (PARI) methodology developed by Hall et al. (1995). PARI methodology revolves around situated problem-solving sessions where participants deploy knowledge in response to particular precursors in real time. As they seek solutions, participants are probed for the reasons behind the actions they elect to take. Then, after executing the proposed action, participants are asked to reflect on and explain the results of their actions. In this way the reasoning processes that are responsible for the knowledge deployment are made apparent. The probes are part of a structured interview designed to reveal relational aspects of the four factors that constitute professional expertise as applied in the context. Participants in this study were presented with tasks and asked to generate plausible hypotheses/diagnosis for the given problem situation. They were then asked to explain the rationale for their hypotheses and finally make diagnostic conclusions.

Subjects. Two groups participated in the study. The first group consisted of four novices (N). The novices were individuals who had veterinary science graduate qualifications but had very limited experience in the profession generally and particularly in using ultrasound for diagnosis. This group largely depended on their domain knowledge of physiology and anatomy, limited contextual knowledge and strategies, which were based around domain knowledge. They presumably used this knowledge base as a basis for defining their diagnostic strategies, using the ultrasound images and display. The second group consisted of four professional experienced ultrasonographers (E). This group comprised individuals who had veterinary science graduate qualifications and a postgraduate qualification in ultrasound and worked with ultrasound tools on a regular basis. The two groups were selected to identify differences in patterns of use of strategies, tools, domain knowledge and contextual/cultural knowledge and skills. Such patterns allow us to study the relationship between the four factors as experts perform daily tasks.

Task development. A professional expert, not a participant in the study, worked with the researchers to establish appropriate tasks by studying occupation surveys in veterinary practice. The tasks identified involved interpreting ultrasound images in three different cases which are outlined below. The above expert generated a list of typical problem types experienced by veterinarians in relation to interpreting ultrasound images. The problem types were grouped into meaningful problem typologies and three cases were identified. These cases were from the same problem typology (abdominal cases) but varied in complexity. Detailed representative problems that cover each of the three cases represented in the problem typologies were designed. This was necessary to assist the researchers to be fully informed about each case. Once all the representative problems for the three selected cases were designed, the expert generated solutions for all the problems in each case. Care was taken to ensure all possible solution paths were considered.

The tasks. Three tasks were identified based on ultrasound images of the abdominal area of dogs. This was necessary to control other variables that interfere with ultrasound; it also assisted in narrowing the scope of the study and thus allowing an in-depth investigation. Each task was developed and recorded on videotape under the direction of the expert, who assisted in the design of the tasks. The tapes also allowed the speed at which the images were displayed on the ultrasound to be controlled.

Task 1. The first task required the subjects to diagnose two large bladder stones in a two-year-old dog. This problem is relatively simple in that the ultrasound technology has the capacity to present clear images of the stones sitting against the fluid in the bladder. This problem represents a good starting point for exploring individuals' current understanding of routine ultrasound procedures and the specifics of the technology (how the ultrasound works on animal tissues and other forms of materials).

Task 2. The second task involved diagnosing prostatitis. This task was more difficult than the first task, in that in addition to the dog's present problem, it had an existing problem of fibrocartilaginous embolism (FCE), and was also previously diagnosed with prostatic problems. These problems may or may not be linked to its presented problem, and can therefore be misleading. The image was less clear because the dog was overweight. Fat tissue causes poor imaging in ultrasound technology, thus making details in the image less readily accessible. The image shows a moderately enlarged prostate. This required the participant to have some understanding of the appropriate size of a normal prostate. Also, the participant needed to be aware of the manner in which the ultrasound technology interacts with the prostate. Knowledge of how 'bright' the prostate should be is necessary*/if the image is brighter than normal it indicates sound wave reflections from possible lowgrade infection. Task 2 presents a complex problem on every level: possible misleading presenting signs; poorer image due to excess fat tissue; and the actual problem is not as obvious.

Task 3. This task was a case of renal failure from prostatic cancer, but there was no definitive diagnosis as the problem is now so complex that an original starting point is obscured. This task was unique amongst the three tasks because the majority of organs are grossly distorted, making recognition extremely difficult. For this reason it makes an ideal last case to view*/very little is provided as frame of reference. Immediate diagnosis from the presenting signs was not possible, as a large number of possibilities existed for the given condition ranging from single organ failure through to the animal having possibly swallowed some large obstructing object. Imaging in this case was necessary to explore 'what was going on'. The immediate imaging problem is that no definite reference point can be found. The bladder is normally targeted as a first imaging reference, and in this case it is easily confused with similar adjacent objects (cystic structures). All organs are distorted. The bladder is irregular, uretae are grossly expanded (hydrouretae), kidneys are 'blown out' (hydronephretic), and there is a large additional mass in the caudal abdomen (cystic structures). The application of prior knowledge gained from the previous problems is of reduced value in cases like this. The complexity of the problem exposes the thought processes of the observer, forcing speculations and inferences.

Procedure. Each participant met with the research assistant (RA) individually, and thus the pair could engage in dyadic interaction, which was audiotaped. Each participant received information sheets containing the presenting signs and symptoms of each of the three problem tasks. All subjects were asked firstly to hypothesize a diagnosis for each task. The participants were then shown the video recording of the ultrasound images for each task and asked to suggest possible interpretations for their diagnosis. The interaction between the RA and the participant was designed as a semi-structured interview allowing the RA to stop the videotape and pose questions to stimulate and request the subjects to diagnose the task. The interpretations proposed by the participants were then evaluated in light of viewing more of the images. Where there was uncertainty about the actions, response and interpretations of the subject, the RA probed further to seek reason for that which was not readily visible. Each participant was requested to make a diagnostic conclusion (if they had not already done so) at the end of viewing each ultrasound video recording.

Analysis. The audiotapes of verbalized diagnostic processes were transcribed and then analysed using NUD.IST (Richards & Richards, 1991), a qualitative data organizing and investigation program that assists in the qualitative data analysis process. This was achieved through a content analysis approach where the content of all transcripts was firstly examined individually by the researcher and an RA and then jointly to synthesize and consolidate their analysis and identify dominant patterns. This process revealed a reasonable initial degree of 66% agreement between the two analysts of the words and phrases and typical patterns. The differences were resolved by discussion. The analysis involved reading all the transcripts and searching for individual words and phrases that reflected knowledge and skills associated with the fours factors of professional expertise. The identified words and phrases revealed 11 patterns of relationships (A K) as shown in Table 1. These patterns acted as an abstract cognitive structure, which pulled responses for the three tasks and two groups together. Such 'top-level' patterns allow analysis at a higher level of abstraction where commonalities in cognitive processes within and between different groups can be identified and meaningfully synthesized. The patterns identified were then used to analyse individual participant's transcripts and to compare and explain the reasoning behind the actions taken by the E and N groups. The analysis considered explaining the different relationships used by the two groups of participants and the outcomes of their actions. It also attempted to map the frequency of different patterns used by the individuals and successful diagnosis. The outcomes of these issues are discussed next.

Results

Table 1 presents typical exemplars of the statements associated with the 11 different patterns. Where the statement mentioned or implied the use of tools and artefacts such as the nature of the scan image, light deflection on different materials such as human tissues, bones, water and stones in the bladder, it was assigned to the factor tools and artefacts . Similarly, the statements reflecting strategies were those where participants were applying search heuristics and inference operators, such as working step by step through the information elicited through tools or their physiological knowledge to diagnose the problems. Participants in this category were more focused on connecting symptoms to plausible diagnoses rather than reasoning through the steps*/it was more a means to an end for them. The step-by-step process included both forward and backward working, depending on the available information. Typically, forward working is considered expert behaviour (see Sweller, 1989) but in a contingent and dynamic world one needs to be flexible to work from both directions. The socio-cultural factors were seen as situations that involved contextual issues such as considering the financial cost of the treatment to the pet owner, seeking to understand the background of the case, and incorporating case history. Statements suggesting seeking validation of diagnosis from senior experts as a professional culture were considered socio-cultural factors*/this can also be viewed as the ‘power distance’ relationship evident in the text of some of the transcripts. It may also be considered as a strategy but the driving energy for such validation, in this case, was the power relationship. Finally, domain knowledge comprised medical sciences and animal physiology and was identified by statements that directly or indirectly made reference to this. Having categorized the transcripts, the interrelatedness of the factors was identified and grouped into the 11 patterns.

Table 1. Exemplar statements for each of the factors of the professional expertise model

Patterns of professional expertise model	Examples illustrating the dynamic relationship of the four factors
A Socio-cultural & Domain knowledge & Tools & Strategies	E2: It’s a really patchy picture of a prostate *[tools]* … so that would really worry me that there is either infection going on, most likely given its history *[socio-cultural]*, or possibly a tumour *[domain knowledge]*. Pretty uncommon to see prostatic cancers really, much more likely to be infection *[strategies]* E3: Just let me have a read … poor dog is depressed, running a fever *[socio-cultural]*… my thinking here is that I am pretty sure he has a para-prostatic cyst, but I would not expect him to have a fever like that *[domain knowledge]*. I am wondering if he has a para-prostatic abscess as well. That one particular image there where the cystic area was really nicely defined, there was one area that was quite ill-defined, which looked more reactive and abscess-like to me *[tools]*. I am thinking abscess, could be tumour with necrotic tissue in it, I would like to have another look from a different angle … *[strategies]*
B Socio-cultural & Domain knowledge & Strategies	E3: When this dog is off antibiotics, not only is there blood in his urine, but he is depressed and more ataxic, which is interesting *[socio-cultural]*. Now if he is depressed as we were talking about in the last dog, thought processes start saying hang on, maybe this is not just bladder anymore *[strategies]*, maybe in fact this is prostate or kidneys which can make a dog systemically unwell *[domain knowledge]* E4: The primary problem is the haematuria and it seems like it has been associated with the management of his urination *[strategies]*, probably an induced-infection due to multiple catheterisation, you should use a catheter closed system *[domain knowledge]*, sorry I am being critical there, it’s the American training coming out in me *[socio-cultural]*
C Domain knowledge & Socio-cultural & Tools	N4: I have been involved in a couple of surgeries to remove bladder stones *[socio-cultural]*. You tend to get these distinct shapes because they rub against each other in the bladder, so you get straight edges and sort of triangular shapes depending on how they roll around *[domain knowledge]*. With the stones here, you can see a definite black shadow *[tools]*
D Tools & Strategies & Domain knowledge	E1: You see these two black tree branching structures ... one has a wall that is not easily defined *[tools]*—that’s the pathic vein *[domain knowledge]*, then the portal vein has a white wall, so if you see two sets of vessels, and one has a white wall, and the other has an ill-defined dark wall, then it has to be the liver *[strategies]* N2: Could it be a kidney? It’s in the right spot *[domain knowledge]*. Yes it is shaped like that, but the middle bit is less dense than the other bit *[tools]*, but that is true too, and it’s about the same shape and its position with reference to … yeah, the kidney *[strategies]*
E Strategies & Socio-cultural & Tools	E4: I guess the next step I would do is to question the owners more *[strategies]* about the frequency of urination, any straining to urinate, because it is limited here. I mean ultrasound is going to tell you structural information *[tools]* but I would do a urine analysis first. Not everyone is going to jump in there and spend $150 for an ultrasound *[socio-cultural]*
F Socio-cultural & Strategies	E3: I’d probably talk to the owners— was there blood in the urine prior to the speying *[strategies]*? If you are given the patient for a second opinion, you have been given a stack of information *[socio-cultural]*; it’s not just straight off the street, that’s a different situation
G Domain knowledge & Socio-cultural	E1: Certainly prostate is high on my list of concerns … he is a 5 year old entire male dog, never been desexed—tsk tsk *[socio-cultural]*. Prostate disease in entire middle-aged and older male dogs is as common as in you and I when we get to 50 *[domain knowledge]* N3: It looks like bladder stones *[domain knowledge]*, but even now, my boss has been out of uni for 12 years, and quite often I will take a case to him and say ‘what do you think, is this in the bounds of normal for you?’, just to get the benefit of another four times more experience than I have *[socio-cultural]*
H Tools & Domain knowledge	E1: That’s the edge of the spleen … bottom edge. The spleen has got like a fibrous capsule *[domain knowledge]*, and so at the edge of that spleen you get a really bright white line, because all the sound waves are more or less hitting the same sort of front at the same time *[tools]*
I Strategies & Tools	N2: It seems that fluid shows up darker and tissue shows up lighter in ultrasound *[tools]*, if that is true then stones would be darker because they are more echo dense *[strategies]*
J Domain knowledge & Strategies	N4: Maybe it is the prostate. I guess *[strategies]* it is sort of in the area for the prostate *[domain knowledge]*
K Socio-cultural & Tools	N4: Well I don’t remember covering any ultrasound theory in my training, but when I’ve watched them do an ultrasound *[socio-cultural]* they go in order from the liver, then stomach, spleen, kidney going across. That is my very limited knowledge of ultrasound procedures *[tools]*

Table 2 presents a summary of how the 11 patterns were used by expert and novice participants. It maps the combination of patterns used by the participants in terms of complex and simple dynamics as they performed the three tasks. Complex dynamics are involved in patterns A E while more simple dynamics are involved in patterns F K. Furthermore, the table also indicates the outcomes of the diagnosis performed by each of the participants on each task as being either successful or unsuccessful. Thus, considering the different combination of patterns used by participants, while pattern A appears to be the most complex of the 11 patterns; it was used in less than 50% of the cases by the experts and not at all by the novices. The summary illustrates a clear demarcation between how the experts and novices used the different patterns

Table 2. Dynamics of the factors of the professional expertise model for novices and experts who were successful and unsuccessful

			Factors of professional expertise model	
Subject	Task	Success	Complex dynamics	Simple dynamics
E1	Task 1	Successful	B, C, D, E	H
	Task 2	Successful	A, B, C, D	G, H
	Task 3	Successful	B, C, D	
E2	Task 1	Successful	B, C	H, I
	Task 2	Not successful	A, B, C, D	J
	Task 3	Successful	B, C, D	
E3	Task 1	Successful	B, C, D	F, H
	Task 2	Not successful	B, C, D, E	F, G
	Task 3	Successful	A, B, C, D, E	
E4	Task 1	Successful	B, C, D, E	
	Task 2	Successful	A, B, C, D, E	
	Task 3	Successful	A, B, C, D, E	
N1	Task 1	Successful	B, D	H, I
	Task 2	Successful	B, C, D	H, I
	Task 3	Not successful	B	H, J
N2	Task 1	Successful	B, D	F, H, I, J
	Task 2	Not successful	B, D	H, J
	Task 3	Not successful	B, C, D	H, J
N3	Task 1	Successful	B, C, D	F, G, H
	Task 2	Not successful	B, E	G, H, I, J
	Task 3	Not successful	B, D	H, J
N4	Task 1	Successful	B, C, D	F, G, H, I, K
	Task 2	Not successful	B, D	F, H, I, J
	Task 3	Not successful	B, C	G, H, I, J

of professional expertise. The most preferred patterns by both groups were B, C and D, even though novices did not achieve as many successful diagnoses as the experts. The results suggest that when the tasks were more complex, as in Task 3, with more information given and more hypotheses possible, more complex thinking was required (reflected by the patterns used to diagnose, particularly by the experts). The reverse was the case for simpler tasks. When participants tackled the simpler tasks (Task 1, for example) they were dealing with less information and could use simpler dynamics. The novices showed more dependence on simple dynamics and in most cases this did not result in successfully solving the task. When they were successful, they had generated the more complex dynamics. When we examine the dynamics more closely, it can be seen that novices are working mainly from substantive domain knowledge and strategies and are attempting to create enough ‘simple’ links to obtain a solution.

Figures 2 and 3 show the frequency of different patterns used by novices and experts in solving all three tasks. The patterns in turn illustrate the dynamics of the four factors in supporting the reasoning and explanations. It also illustrates the very diverse yet legitimate combinations of patterns which can still produce a successful

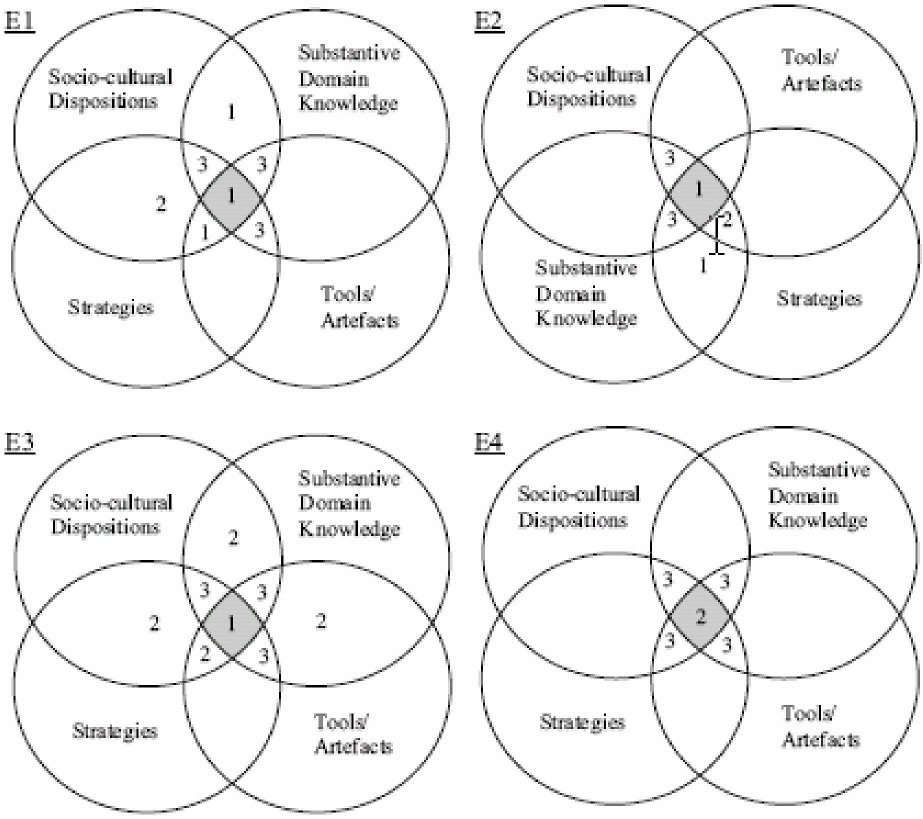

Figure 2. Patterns exhibited by experts

diagnosis. All experts had high frequency of use of the complex interaction (patterns B, C and D) of domain knowledge/tools and artefacts and socio-cultural dispositions, whereas the novices, being recent graduates of the veterinary science course, had expertise in domain knowledge and hence it had the highest frequency. It is also interesting to note that even at a simple dynamics level, novices made limited connections between tools/artefacts and strategies (pattern I).

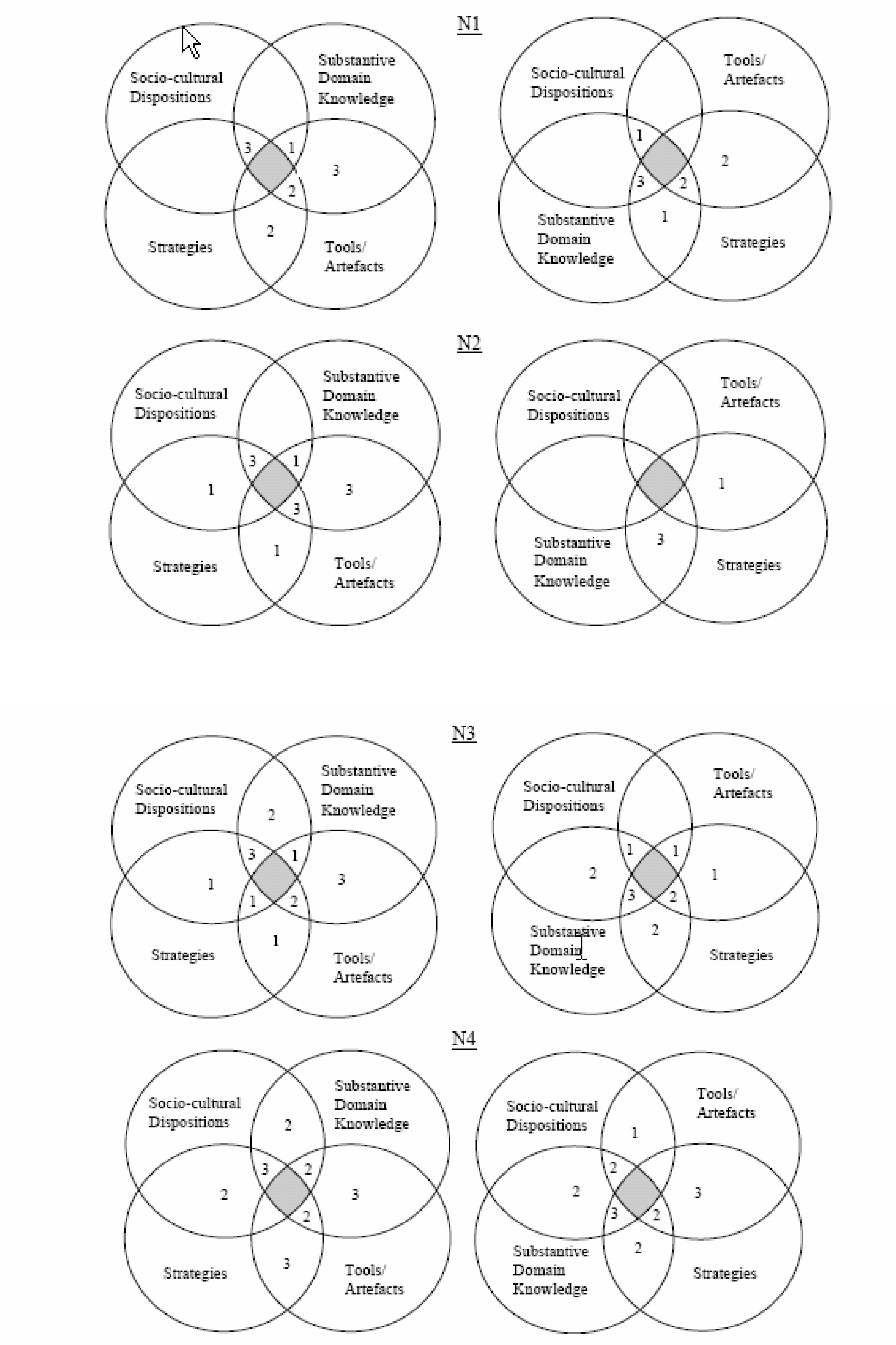

Figure 3. Patterns Exhibited by Novices

Discussion

We hypothesize that building the professional capacity of workers in a contingent and dynamic world cannot happen unless the nature and levels of thinking and reasoning necessary to support such professional expertise are fully appreciated. The four factors identified in this paper are very diverse and complex, and previously have mainly been studied as separate entities. The complexity and traditional boundaries demarking knowledge and expertise also contribute to the current fragmented approach. However, this paper is an attempt to encourage the development of a comprehensive model of professional expertise that includes knowledge, skills and attitudes from socio-cultural perspectives, subject domain content, strategies, and tools and artefacts. The idea of a dynamic synchronous and asynchronous interplay between the four factors is central to understanding the nature of professional expertise and it concurs with Bandura's (1997) 'reciprocal determinism'*/a conceptual mechanism for explaining the meaning-making process.

Previously, guided by a constructivist paradigm, the reciprocity was perceived as being between the individuals and the strategies, the individuals and the tools, or the individuals and the domain knowledge. However, as can be evidenced in the results, it appears that there are possibilities for interactions between individuals, tools, strategies and domain knowledge that are over and above the interpretative input of a professional expert. For example in Table 1, 'pattern I' shows that the strategies adopted by the participant are dictated by the capacities of the tool, more than the individuals' interpretation of the displayed image. Participants who subscribed to this pattern had recognized the need to identify acoustic shadowing displayed by the tool in order to identify and make meaning of the displayed image. A further example of the significant role played by tools can be seen in 'pattern H' where the interaction is between the domain knowledge and the tool. While the participants know what a spleen is and what it looks like, it appears very different on an ultrasound image and thus presents additional complexity in making sense of the displays and consequently the diagnosis. The domain knowledge influences the design of the tools but technology can also influence how we reconstruct what constitutes domain knowledge to include the capacities of the tools that we use. We suggest that different tools have different epistemologies and contribute differently to expert performance. In 'pattern D' the statement illustrates how the inherent capacity of the ultrasound (the image) and domain knowledge jointly influences the strategies adopted by experts.

The identification of structural features and value features (colours and shades) is possible only because of the graphical images generated by the ultrasound, and the interpretation of the image is guided by the epistemology of the tool.
Thus, the singular directionality of the interaction*/from individual to each of the four factors*/may need revisiting as we begin to acknowledge the existence of meaning and an epistemology contained in each of the four factors. The meaningmaking process is still a human act but the tool extends and assists with the process; the other three factors are also influential.

The interrelatedness of the four factors in professional practices can be seen in the manner in which the participants used different combinations of the four factors and the frequencies of such combinations, as illustrated in Table 2 and Figures 2 and 3. The most complex of these interrelated patterns is 'pattern A', which encompasses all four factors; however, it was not used much by the participants, including the experts. While it may be all encompassing, it may not be necessary for some of the tasks as they were diagnosed successfully without having to depend on pattern A. Thus, successful diagnosis of a task is not necessarily dependent upon the most complex reasoning. It could be achieved through a compilation of a number of lower order combinations of factors*/thus making a case for asynchronous processes that draw upon past knowledge and experiences. Successful diagnosis seems to lie in the ability to recognize key information from the different factors as they apply to the task in hand, including those interactions that facilitate successful diagnosis. As indicated in the results, all successful diagnoses were those where the participants used a number of different factors. The significance of domain knowledge can be seen in patterns A   D, but political ideologies such those guised as situated cognition make it difficult for most people to appreciate the role of such knowledge. It may be argued that situated cognition advocacy was promoted to take power (having the knowledge and skills) from the elitist universities and colleges and place it in workplaces where it can be shared by the broader public. This is not intended to undermine the value in situated learning arguments but places in context possible socio-cultural drivers to redefine professional expertise as being mainly what you can see and/or do.

Similarly, a tool is often seen as an instrument and not something that has its own knowledge or cultural influence, which can have ethical implications such as privacy, access and equity. For instance, the choice to use complex tools often means increased cost, and, as one of the participants noted, professionals should be conscious of how their decisions can have financial consequences for their client. While having the capacity to correctly diagnose the symptoms, one should be sensitive to the financial demands on their clients*/a social and moral responsibility. The most common patterns that illustrate the interrelatedness of the factors are patterns B and C. They jointly cover all four factors and were used more frequently than any other patterns. However, the use of complex dynamics and simple dynamics provides an interesting perspective in that the novices, despite using patterns B and C, also used a large number of patterns from the simple dynamics. They seemed to be unable to compile lower order reasoning into more complex dynamics and consequently achieved fewer correct diagnoses.

The recognition that professional practice is multifaceted in nature and mutually dependent on the different factors can be seen in the frequency of use of patterns B, C and D, which collectively encompass all factors and thereby allow a thorough and often successful diagnosis. For instance, the role of theoretical domain knowledge, which in recent years has been unintentionally downplayed in favour of contextual and cultural knowledge, can undermine the confidence of practitioners. The results of this study illustrate the interrelatedness of the different factors, including domain knowledge, as being pertinent to expert behaviour in professional practice. Strategies such as risk taking and conjecturing may not be common to all cultures.

For instance, in many Asian cultures the notion of 'loss of face' is so strong that it may prevent experts from engaging in the exploration of an option, for fear of being ostracized if it is discovered that they were not sure of what they were doing, particularly when dealing with the lives of pets. Similarly, mentoring can be viewed as either a means to support novices or controlling others from becoming too innovative. The constant checking with experienced practitioners (the boss) as noted in 'pattern G' seems to indicate a power distance which is more prevalent in some professional cultures than others. Developing expertise through mentoring by merely recognizing the overt behaviours or demonstrations may not be sufficient to facilitate development of self-consciousness, which permits one to make critical distinctions between one's own psychological reactions and external events. Expertise is viewed, often mistakenly, as merely the ability to perform a physical activity, focusing on external events, as evidenced in much competency-based training.

Conclusion We argue that the conceptualization of professional expertise that pervades all four factors is the important issue*/not whether one factor is more appropriate than another, or whether individual cognition is more important than other cognition systems, or whether one knowledge type is more important than the other. The emerging complexity of professional expertise will not allow us the luxury of adopting only one of the given factors; rather, it expects us to function equally effectively in a number of factors. The fragmented approach to understanding professional expertise has tended to cause much tension in identifying the most appropriate approach to developing expertise. We suggest that singularly focused research cannot form the basis of our understanding of something that involves a dynamic interaction between a range of different, yet interrelated, concepts.

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