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How might mathematics education be used to improve diagnostic reasoning?

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The evolution and activities of all professions have been driven and directed primarily by their responsibility to the societies they serve [1]. Medicine is no exception and there is broad consensus that the medical profession exists to serve both individual patients and society in general [2]. Schön has broadly defined these professional activities in medicine as "instrumental problem-solving made rigorous by the application of scientific theory and technique" [3]. Implicit in this definition are two concepts: The activities that the profession performs and the knowledge base that supports those activities. We believe, in the case of medicine, that the instrumental problem-solving activity is diagnostic reasoning and that there is much to be gained from further understanding how that activity and the knowledge base interact with one another to influence learning and practice.

Diagnostic reasoning offers the ultimate value that physicians add to the healthcare equation, as it is the one competency that still sets the medical profession apart from most other health care professional activities. A comprehensive summary of research into diagnostic reasoning is well beyond the scope of this essay, but we would summarize a couple of key themes by stating that diagnosis is heavily dependent on context specific knowledge/experience and that the reasoning processes that are engaged for any given case shift in response to many variables including age, time pressure, fatigue, and similarity to previously seen cases [4]. Despite considerable study into how knowledge is organized and how different forms of knowledge are used, there has been little exploration of how these two concepts of activity and knowledge interact. In the interest of prompting new domains of exploration, we would like to make some observations on specific epistemological issues we feel need clarification in this regard.

One distinction that is derived from cognitive psychology, but has not generally made its way into the diagnostic reasoning literature, is between a) procedural, or problem-solving knowledge [knowledge of how to do things] and b) declarative, semantic or conceptual knowledge [knowledge of things] [5, 6]. By way of analogy, to ride a bicycle effectively (procedural knowledge) does not require knowledge of the mathematical relationship between power, torque and angular velocity in the crank set of the bike (conceptual knowledge). Further, those with such knowledge cannot necessarily ride at a high level. In a medical context, it might be the case that diagnostic reasoning (problem-solving) utilizes a fundamentally different kind of knowledge from one's conceptual knowledge (e.g., declarative knowledge of the biomedical sciences such as anatomy, physiology and microbiology). Extensive knowledge of these domains in isolation would not enable one to make a diagnosis. Conversely, many lay people, without any formal biomedical knowledge, can diagnose simple conditions they have encountered in their personal experience (i.e., they can problem-solve, albeit at a superficial level). When examining diagnostic practice, the medical education community has not generally distinguished rigorously between these two domains.

For example, Blisset et al. conducted a study asking whether schemas should be used in teaching [7]. The educational psychology literature defines a schema as 'an organized body of information about some distinct domain of knowledge' (i.e., in terms that indicate purely conceptual knowledge) [5]. Blisset et al. defined schema-based reasoning as 'a process in which key clinical features are used to include or exclude sets of diagnoses.' They randomized second year medical students to learn four cardiac diagnoses using either schema-based or traditional instruction on a high-fidelity cardiopulmonary simulator and found that although learning time and factual knowledge gain did not differ, diagnostic success was higher in the schema-based instruction group. These are practically useful findings, but it is clear that the authors used the word 'schema' to refer not only to conceptual knowledge and its arrangement in memory, but also to specific problem-solving algorithms (procedural knowledge), without attempting to distinguish between the two.

Most often when doing things on a day-to day basis we just have to know 'how to'. How many of us, for example, could explain the detailed workings of an internal combustion engine while driving to work? But sometimes, particularly in situations demanding expertise we have to know the concepts behind the 'how to'. To succeed in the Tour de France not only requires one to be an expert cyclist in a 'how do I ride a bike' sense but also requires detailed conceptual knowledge of determinants of maximum sustainable power. Research in the field of mathematics education suggests that paying closer attention to the relationship between procedural and declarative knowledge might help optimize teaching strategies. Using qualitative methodologies, Voutsina investigated the different types of arithmetic knowledge that young children utilize when solving a multiple-step addition task [8]. The study revealed a dynamic relationship between children's developing representation of the task, their improved procedures and eventually their more explicit grasp of the conceptual aspects of their strategy, suggesting that conceptual and procedural knowledge in mathematics develop iteratively. Turning such models into an educational intervention, Rittle-Johnson and Koedinger evaluated the instructional benefits of an iterative lesson sequence (alternating between concepts and procedures) compared to a concepts-before-procedures sequence for students learning concepts related to decimals and associated arithmetic procedures [9]. Students in the iterative condition gained significantly more knowledge of arithmetic procedures, including the ability to transfer the procedures to problems with novel features.

In medicine, none of the many studies on the role that basic science knowledge plays in diagnostic reasoning have specifically cast diagnostic reasoning as a distinct form of procedural or problem-solving knowledge that might best be learned iteratively with conceptual knowledge [10, 11]. The work of Woods et al. comes closest in that they broke the mould of looking for the influence of conceptual biomedical knowledge by examining when such concepts are mentioned during diagnostic activity and turned their attention instead to how conceptual knowledge might influence learning in a way that impacts on such activity [12]. To continue the above analogy, the Tour de France rider might benefit greatly from layering learning about mechanical and physical concepts iteratively with physical training; whether or not such concepts would be thought of by the riders during the actual race while gritting their way up a mountain is another matter entirely.

We would suggest that what has traditionally been called 'vertical' integration more appropriately be

viewed pedagogically as the relationship between procedural and conceptual knowledge [13]. If the integrated teaching and learning of biomedical science and medical problem-solving can be shown to be more effective than their separation in the classroom, this would provide the ultimate repudiation of the century-old Flexnerian 'two-plus-two' doctrine while also supplying additional cogent evidence for the value of basic science even if experienced practitioners' descriptions of their reasoning processes were completely void of biomedical concepts. Recent calls for pedagogical innovations supporting integrated learning in medicine are a move in this direction, but they await formal evaluation of educational effectiveness [14].

While biomedical knowledge might support diagnostic reasoning, where the optimal balance lies remains unclear. As will be well recognized by readers of this new journal, there has been an exponential increase in the amount of biomedical knowledge in recent decades, thereby making it unreasonable to expect any medical student or practitioner to "know" everything in the traditional sense of the word. A century of educational practice since the Flexner report has helped promote the inclusion of much of this material in undergraduate medical curricula despite the real potential for information overload, dooming some of what is learned to be forgotten [15]. While everyone wants their favourite topic to be included in medical school curricula, none of the reports we have seen with regard to the biomedical knowledge that should be taught in medical schools have attempted to define or classify this conceptual biomedical knowledge in the context of the reasoning process of expert physicians. All these reports have either been opinion surveys or simply opinions of students, practicing physicians, or biomedical scientists teaching in medical schools [16–18]. How much of this biomedical knowledge is necessary for solving clinical problems, and how it might be classified, is unclear and awaits further investigation. What is clear from a cognitive load perspective is that the more biomedical knowledge students are forced to keep active in working memory, the less working memory will be available for problem-solving.

In sum, we have argued that diagnostic reasoning is the raison d'etre par excellence for the medical profession, but more importantly, that diagnostic reasoning as a defining professional activity likely requires two kinds of supporting knowledge: conceptual and procedural. We believe that the medical literature to date has not clearly made this epistemological distinction. We also believe that what has traditionally been called vertical

integration should be more accurately viewed (and investigated) as the iterative integration of conceptual and problem-solving knowledge, and that the biomedical knowledge taught in medical schools should be defined in the context of diagnostic reasoning. As in the animal and plant kingdoms, we hope that the cross-pollination of ideas (in this case from mathematics education) will strengthen our own medical education species and help advance research in diagnostic reasoning.

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