VIEWPOINT

The challenge for basic science education in problem-based medical curricula

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Abstract

There has been intense debate about medical curriculum reform since the early 1950s. The last 25 years have seen a steady shift toward problem-based learning curriculum design in schools of medicine and allied health sciences. This trend has been less challenging for clinical departments than for departments of basic science, where it has often evoked anxiety, antipathy, lack of cooperation, and general mistrust. This appears paradoxical, as problem-based learning (PBL) is promoted as an improved method of integrating scientific concepts, and the advances that drive much of modern medical practice are advances in the basic sciences. While proponents of PBL argue that the approach promotes better integration and use of scientific concepts, the evidence, such as it is, is against this. As well, other evidence suggests that clinicians do not use basic science concepts extensively in their practice. This then questions the utility of scientific knowledge in a medical curriculum. This article examines this notion of utility (the quality or state of being useful), to establish some ground rules for what does, and does not, possess utility, and to present strategies to develop specific objectives from general statements concerning utility. Understanding of biologic and pathologic processes becomes of central importance and arguably possesses utility. If it is both required and evaluated, such understanding necessitates mastery of basic science concepts. Previously, the presentation of the basic sciences in medical curricula has emphasized the acquisition of knowledge rather than its use. Such learning has been perceived to lack utility; strategies to enhance the value of studying basic science concepts are suggested. If the importance of objectives in the basic medical sciences is accepted, these objectives should be achieved early in training, maintained at exit from medical school, and revisited in continuing medical education. The process of change in medical education initiated by Abraham Flexner early in this century remains incomplete. One reason why curricular changes have proved frustrating to basic scientists is that much of clinical medicine remains unnecessarily unscientific. Until clinical medicine itself changes, the utility of science in the training of a physician will remain difficult to demonstrate.

Résumé

La réforme des programmes d'études en médecine fait l'objet de débats animés depuis le début des années 50. Au cours des 25 dernières années, les facultés de médecine et de sciences paramédicales ont adopté graduellement le concept des programmes d'apprentissage fondé sur les problèmes. Cette tendance a posé moins de défis aux départements cliniques qu'aux départements de sciences fondamentales, où elle a souvent suscité l'anxiété, l'antipathie, le manque de collaboration et la méfiance générale. Cela semble paradoxal, car on préconise l'apprentissage à base de problèmes (ABP) comme façon améliorée d'intégrer les concepts scientifiques, et les progrès qui sont les éléments moteurs d'une grande partie de la pratique moderne de la médecine sont ceux des sciences fondamentales. Même si les partisans de l'ABP soutiennent que cette façon de procéder favorise une intégration et une utilisation meilleures des concepts scientifiques, les données indiquent que ce serait plutôt le contraire. D'autres données indiquent aussi que les cliniciens n'utilisent pas à fond les concepts des sciences fondamentales dans l'exercice de leur profession, ce qui soulève des questions au sujet de l'utilité des connaissances scientifiques dans un programme d'études en médecine. L'auteur de cet article examine ce concept de l'utilité (caractère de ce qui est utile) afin d'établir des règles de base sur ce qui est utile et ce qui ne l'est pas et de présenter des stratégies d'élaboration d'objectifs précis à partir d'énoncés généraux sur l'utilité. La compréhension des phénomènes biologiques et pathologiques devient d'une importance capitale et l'on peut soutenir qu'elle est utile. Si elle est à la fois obligatoire et évaluée, cette compréhension oblige à maîtriser des concepts des sciences fondamentales. Auparavant, la présentation des sciences fondamentales dans les programmes d'études en médecine mettait l'accent sur l'acquisition de connaissances plutôt que sur leur utilisation. On croit que cette façon d'apprendre manque d'utilité et laisse entendre

qu'il faut adopter des stratégies afin d'améliorer la valeur de l'étude des concepts des sciences fondamentales. Si l'on accepte l'importance des objectifs des sciences fondamentales en médecine, il faudrait les atteindre au début de la formation, les garder au départ de la faculté de médecine et y revenir dans le contexte de l'éducation médicale continue. Le changement de l'éducation médicale amorcé par Abraham Flexner au début du siècle demeure incomplet. Les changements de programmes d'études ont été une cause de frustration pour les spécialistes en sciences fondamentales notamment parce qu'une grande partie de la médecine clinique demeure inutilement non scientifique. L'utilité des sciences dans la formation du médecin demeurera difficile à prouver tant que la médecine clinique elle même ne changera pas.

Introduction

More than 60 medical schools worldwide have switched to problem-based learning (PBL) in some shape or form.[1] This approach to learning contains little that is new for clinical instruction, in which much of the educational experience has traditionally involved small groups discussing clinical problems. However, it provides a major challenge for basic science departments, in which, at least recently, most teaching has been structured around lectures and the students' main problem has been to score well in examinations. The purpose of this article is to review briefly the nature of learning in a PBL curriculum, to explore the potential for a negative impact on education in the basic medical sciences in switching to PBL, and to consider strategies to overcome this negative impact — to the extent that this is desirable.

Three revolutions

Three revolutions in medical education in North America can be identified. The first followed the Flexner report of 1908;[2] the second occurred at Case Western Reserve University in 1952; and the third, which saw the formal introduction of PBL to an entire curriculum, occurred at McMaster University in 1969.[3] Although these reforms may be seen as purely educational, the impetus for them was change in society as much as a desire to improve teaching.

Influenced by the high quality of German medical science, Flexner and his colleagues proposed changes to strengthen the academic and scientific components of medical education, and this included strengthening basic science departments. As a result of his report, many medical schools that were unable to provide credible academic programs were closed (by the mid-1920s the number of schools had decreased from 55 to 23), and major growth occurred in departments teaching the basic sciences. Departments of anatomy, physiology, biochemistry and pharmacology prospered, as did departments affiliated with clinical laboratories (pathology, microbiology and clinical chemistry). Their corresponding learned societies grew, and the research that supports much of our current knowledge of disease became a major preoccupation of schools of medicine.

Growth in medical science, and in medical knowledge generally, led to pressure on the curriculum. At the same time, the power and independence of the basic science departments became associated with fragmentation and duplication of teaching. In the early 1950s, many students were veterans of World War II, who were impatient with apparently irrelevant coursework. Stimulated by the US National Institutes of Health, it was in this climate that Hale Ham launched the program at Case Western Reserve University that emphasized integration, clinical relevance, and an introduction to patients for students at the beginning of their training. The impact of the Western Reserve experience is hard to assess, but, in general, the problems of curriculum overload and the emphasis on knowledge rather than on its use, remained.

Against the background of the Vietnam War, the 1960s were turbulent times at universities in North America. Student pressure against authority and perceived irrationality was not limited to politics. It was also a time for experimention in education. In Canada, universal health care was arriving and, in Ontario, a shortage of doctors was forecast. Against this background, a new school at McMaster University in Hamilton, Ontario, established a different direction under the guidance of John Evans and his colleagues. The training given the medical student was to be the start of a lifetime of continuing education. Lectures were not to be a major medium for transmitting knowledge; clinical contact would start as soon as students entered the program; and study of a series of "biomedical problems" would define both the basic science and the clinical curriculum. Students would work in groups under the guidance of a tutor, and they would be individually responsible for acquiring the knowledge that they, and their group, identified as necessary to deal with each problem (self-directed learning). The qualities desired in medical graduates were defined, and included the ability to succeed in this process of independent learning. Knowledge was not be to allowed to dominate these other important attributes in the assessment system, and methods of evaluation that emphasized content were avoided.[3] As stated above, this approach has been adopted — with various modifications — by more than 60 schools worldwide.[1]

Despite these revolutions in medical education, and despite vast amounts of energy expended by learned societies on reports and journal articles, there is only limited evidence that these or other changes in training programs have affected either the quality or competence of graduates.[4,5] This article suggests that PBL may have achieved less than its full potential because losses in communicating basic science concepts must be set against gains in other areas.

Defining problem-based learning

It is necessary to review what is, and is not, meant by PBL. The essence of PBL is that problems in human health and disease define both learning objectives arising from a specific problem, and non-objectives, which can be excluded from learning because they are not relevant to the problem under study. Both new and old information is integrated into the definition, analysis and correction of the problems presented. Proponents of this system argue that concepts or information from the basic sciences will be recognized by students as learning objectives and studied, with help from faculty ("resource persons"), as required, and will be integrated into clinical problems. Critics of the system question the ability of student groups to ask the right questions in order to uncover the scientific basis of the problems, and suggest that student groups will gloss over difficult scientific ideas in favour of clinical material of more immediate interest.

Consider the following scenario, which is typical of problems given to students starting their study of medicine:

"A 34-year-old mother of 5 children brings her youngest child, aged 7 months, to the health centre where you are working. The child has vomited twice in the past 24 hours and passed five greenish stools in the same period. The child looks ill and has refused the usual formula feeds over the past 2 days."

Various strategies have been defined by different PBL schools to lead their students from a scenario such as this one to appropriate learning. In general terms, the students consider the implications of the items of information supplied ("issue generation"), generate hypotheses to connect these items, and recast the problem (a) into increasingly technical language and (b) into pathophysiologic explanations. (c) Broader social and political issues are considered and, finally, (d) ways and means to prevent this and similar problems are discussed and studied. This problem should generate objectives in the domains of biology, behaviour and population health. Learning issues are then defined from basic or clinical science, from population health or from the social sciences, and some of these are selected for study. A variety of closures to the problem are possible: *the object is not to define a new and unique solution to the problem* (problem solving) but, rather, to learn how to handle information and what information to handle in a process roughly parallel to diagnosis, investigation and management in clinical medicine.[6] Students generally aim to reach both the understanding and the solutions available in standard textbooks, but learning may also be enriched by accessing current literature and electronic media.

In this system, learning can occur only after an objective has been defined: this requires that a group of students working on a problem have sufficient insight to see the opportunities that exist for defining their objectives. Most faculty will agree that this depends on the prior preparation of the minds of the students; admission requirements vary widely among the PBL schools. Further, the curriculum changes that have ushered in PBL have also tended to move clinical teaching (and clinical teachers) toward the beginning of the curriculum; thus, it would be surprising if students did not see the reasoning strategies apparently used by experienced clinicians as their guide as they consider the problems provided by the curriculum.

The extent to which students in a PBL course do identify the issues intended by faculty has been studied[7,8]: students do overlook some issues, but they also generate issues overlooked by their faculty. Variable amounts of guidance, such as course manuals and "tutor guides," are usually provided to address possible omissions.

As students work with their clinical guides and mentors, they observe that medical practice is based on combinations of four reasoning strategies:

1. Published taxonomies, procedures and algorithms, including lists of differential diagnoses, guidelines for management, catalogs of adverse effects of drugs, recommended antimicrobial agents, etc.
2. Statistical ("evidence-based") rules and probability theory, in which clinical-trial data and critical appraisal of the quality and generalizability of trials drive clinical decisions. The rapidly growing importance of this area is emphasized in a recent editorial.[9]
3. Biologic, psychologic and social plausibility, in which, in the absence of other guidance, the physician must diagnose, investigate and manage each case as best possible on the basis of the knowledge available to him or her.
4. Personal heuristics, procedures and algorithms, built up through a combination of education and experience.

With the exception of (3), above, and possibly (4), these clinical problem-solving strategies place little demand on the material taught in basic science courses, yet proponents of PBL assume that this is how students will generate their basic science objectives.

Utility

In terms of their utility (quality or state of being useful), basic science concepts fulfil the following objectives:

- To support strategies (3) and (4), above.
- To provide *understanding* of the biologic basis of disease as a context for learning.
- As a background to reading medical literature in order to *understand* the significance of new advances.
- To *understand* how (and whether) a drug will act.
- To be able to explain concepts in health and disease to patients (to help them to *understand*).
- As an antidote to irrational thinking about health and disease, which currently supports a growing interest in alternative medicine.

It has been shown that, while expert clinicians use simple "rule-of-thumb" strategies for common problems, these may fail in complex situations; when solutions are not immediately obvious, clinicians will fall back on basic principles.[6] In PBL, we expect our students to start with basic principles, in the belief that they will then identify learning objectives in the basic sciences. But will they do so in the absence of role models?

In 4 of the 6 objectives listed above in which science possesses utility, understanding appears as the justification for studying basic science, but understanding is difficult both to define and to measure. In this article, *understanding* will be used to mean the possession of a theoretical framework into which new information can be inserted, with the new material linked logically to the old. As each new problem is understood, the student's theoretical foundation is expanded. Difficult though it may be to rigorously define *understanding*, the importance of this attribute cannot be over-emphasized. Understanding is intellectually satisfying and, by providing context for learning, appears to play an essential role in establishing memory. In this sense, understanding possesses utility.

PBL and the acquisition of concepts in the basic sciences

What has been learned concerning the relative merits of PBL and traditional curricula in terms of outcome measures? A confounding factor will be that most PBL schools still require their students to succeed in examinations of some sort. Examinations have a major steering effect on the curriculum and may stimulate students to study the basic sciences, much as they would if they had formal courses. Again, this tends to be knowledge acquired separately from its application to clinical problems. Hence, such examinations could be seen as defining a parallel curriculum. In their reviews of the literature, Vernon and Blake[5] and Albanese and Mitchell[4] identified gaps in the knowledge base as a feature of PBL curricula, at least in some studies.

Schmidt, Dauphinee and Patel[10] reviewed studies that have addressed possible differences between the achievements of students in PBL and those in traditional curricula. Using performance on multiplechoice questions to judge academic achievement, differences at the end of training tended to be minimal but were biased toward the traditional curricula. Canadian (McMaster University) and Dutch (Limburg University) studies have suggested that clinical competence was enhanced in students taking PBL curricula, although an Australian study failed to find this difference. No solid evidence is available for or against better integration or use of basic science information in clinical practice as a result of curricular changes introduced over the past 40 years.

Pharmacology deserves special comment, because prescribing drugs is a central part of medical treatment and has, in addition, a well-defined scientific basis. It is also well documented that physicians do this badly. However, despite efforts to incorporate drug-related issues into the problems, McMaster University students have consistently identified this subject as being relatively neglected in their undergraduate training.[11] In contrast, Sivam, Iatridis and Vaughn[12] describe the introduction of pharmacology to the PBL curriculum at Indiana University. At McMaster there is no content-specific evaluation; at Indiana, there was. This exercise was described as "successful" because the students acquired the content necessary to pass their examinations. Whether this implies that the students were able to use the information they gained in handling or understanding pharmacologic aspects of clinical problems is not documented.

Lack of evidence for or against efficacy has not shaken the belief of many leaders in the field that change toward PBL should occur. This view has been embraced by the Association of American Medical Colleges in its *Report on the General Professional Education of the Physician* (GPEP).[13] As well, the American Society for Pharmacology and Experimental Therapeutics has worked particularly forcefully in this direction.

If it is accepted that PBL provides a way to define what is worth learning as well as what is not, students can be expected to apply their own criteria of utility to select some topics for understanding, while others are ignored. For example, given a problem involving heart failure, studying Starling's curves is easily perceived to be useful, since Starling's curves appear to explain failure of ventricular function. In contrast, study of mitochondrial function in the failing myocardium fails at present in this regard. Applying such criteria of utility permits students to ignore the extensive body of knowledge concerning this latter topic. Unless students perceive the 6 objectives previously defined as important for them at their stage of learning, the related learning objectives will be overlooked.

Returning to the issue of utility, but emphasizing only aspects relevant to the basic sciences, 2 broad areas can be defined: the first has "understanding" as its sole utility, the second embraces material directly related to the practice of clinical medicine. For example, students must learn what questions to ask (history taking), what signs to elicit (examination), what mechanisms to suspect (pathophysiology), what investigations to request and what treatment(s) would be appropriate. (These activities do not occur separately; they are part of the process of exploring hypotheses.[14]) The distinction between "doing" clinical medicine and understanding what is being done is central to the arguments in this article. If an observer watches an experienced clinician at work, the questions asked, the signs observed, the investigations ordered and the treatments prescribed can all be monitored, but the theoretical framework (*understanding*), defined above, is less readily accessible. It is postulated that the distinction between these 2 categories of learning is central to any neglect the basic sciences might suffer in PBL curricula. No defence need be advanced for the *utility* of those skills observed in an experienced clinician: this is the practice of medicine. This article suggests that acquisition of understanding is a part of the foundation for this experience.

The definition of *understanding* provided earlier in this article emphasizes the role this plays in the learning process: without the framework of knowledge referred to, further growth (learning) may be difficult or impossible. Thus, students of medicine must possess a sufficient *understanding* of physiology, biochemistry, microbiology, pharmacology, etc., to permit this further growth. This statement is not helpful in defining how *much* of these subjects should be mastered, as no limit is set or implied. In the important GPEP report, teachers were urged to reduce the teaching of detail in basic science courses and, instead, to teach "broad concepts." Unfortunately, these have never been defined. If it is acceptable that physicians do not need to understand what they do (whether to ask a question about a symptom or use a drug), then no justification can be made to use scarce resources to support education in the basic medical sciences. But most would agree that this is not acceptable, because physicians hold doctoral degrees from universities, are regarded as educated professionals, are required to explain their actions to their patients, and, most important of all, are expected to possess a theoretical framework that permits them to advance their own education as medicine advances.

Using broad concepts to generate objectives in PBL

Are there useful lessons to be found in the way scientific concepts are taught in courses other than medicine? In the study of mathematics, chemistry or physics, instruction is provided in the principles of these disciplines (for example, the theorems of mathematics). Problems are then provided that illustrate (in their solution) the use of these principles or concepts, and little credit is usually given for the ability to memorize the basic principles or theorems without being able to use them. (This is regarded by some as an example of PBL.[15]) Instead, performance is assessed from the student's ability to choose the correct theory and use it to solve a problem. Note that the objective is utility — the ability to use knowledge (of the theory) to solve problems.

Why should the same approach not be used in, for example, physiology? Much of physiology is concerned with well-defined processes such as homeostasis. Many controlled systems can be rigorously described using general principles. An intensive variable, a sensor, a feedback loop, one or more comparators and effectors comprise such a system. Using analogies drawn from engineering, the system has "gain" and may have a "set point." This outline could be presented, together with illustrative examples. The course objective could then be not simply to recall this knowledge, but rather to be able to apply it to any of a variety of systems. Instead, blood pressure, blood glucose level, metabolic rate and body temperature, to name a few, have been taught separately and in detail, without any guarantee that the student has learned the *utility* of the broad concept: the use of the concept to make predictions concerning a system *or clinical situation* not previously encountered.

An elegant example was provided recently in a review of hypothermia in the perioperative period.[16] The problems described could well have been posed to undergraduate students:

> "Body temperature is regulated. If you are told that general anesthetic agents *decrease the gain of the system* predict problems that may occur during surgery and what might be observed during recovery from anesthesia. How could these problems be avoided?"

Consider another example: In generating objectives in the basic sciences, drug therapy provides fertile ground, as most drugs work at a molecular level to alter organ-system (physiologic) function. I have published an introductory clinical pharmacology textbook based on clinical problems.[17] A set of 10 questions is provided, which embody the essential concepts of clinical pharmacology. The student is urged to apply these questions to each situation in which drug therapy is contemplated; the questions come with the qualifier that, if information is not required to answer one of the questions, it is likely not required at all. Thus, the student is supplied with broad concepts that allow her or him, during learning based on clinical problems, not only to build a knowledge base and acquire understanding, but also to avoid unnecessary study.

I submit the following: (1) The preceding paragraphs are concerned with those broad concepts in biologic science as applied to medicine that medical educators have been urged to adopt by the authors of the GPEP report. (2) Training learners to use such science should follow more the methods of modern chemistry, mathematics and physics and less the approach of 19th-century descriptive biology. (3) Not all basic science is currently amenable to this approach; some areas (e.g., gross anatomy) remain descriptive.

At this point, we return to the problem of the sick infant and introduce a strategy to link this vignette to specific and useful objectives in the basic sciences: the strategy proposes that a small number of global questions will direct students to learn the essential concepts. The first part of *Harrison's Textbook of Medicine*[18] is constructed around what are termed "cardinal manifestations of disease" (CMD). In this problem, diarrhea and vomiting are 2 such CMDs. Confronted with a problem in human health, the student is directed to "*understand* the physiology, anatomy, etc., that underlie the CMDs." (The identification of CMDs lies in the domain of clinical skills and is not considered here.) Deviations from normal (pathophysiology) are identified, and rational approaches to correcting these (treatment) suggested. In ordering tests, the student is directed to understand the basis of the test, and to consider its sensitivity, specificity, possible adverse effects and cost. No great ingenuity is required to formulate such directions, which provide a link between problems and learning objectives. The student is not told what to learn, but rather shown how to behave when confronted with a problem.

It is not possible to define any upper limit to "understanding," but it is possible to demand that a student demonstrate a theoretical framework of understanding (e.g., of diarrhea), which could be judged against a minimal standard of competence. What I have attempted to do in the foregoing paragraphs is to suggest some principles for curriculum design in terms of problems and process rather that defined knowledge. How, then, should the problems be chosen? Only general answers are possible; the problems should be shared among different organ systems and among different academic disciplines; all fundamental pathologic processes should be represented; some conditions should be assigned priority based upon geographic and cultural factors; and the problems should be clinically realistic. The temptation to "cover everything" must be avoided. Gaps are essential; if they are absent, the curriculum is overloaded.

Two issues remain to be addressed: the first deals with prerequisites to a PBL course in medicine, such as discussed above, and the second with the value of these supposedly utilitarian objectives once physicians have graduated from their medical schools. First, physics, chemistry and mathematics — the "foundation sciences" — each provide concepts without which it is impossible to understand material encountered in the basic sciences more immediately related to clinical medicine, physiology, biochemistry, anatomy, pharmacology, etc. Osmosis, transmembrane potential and acid-base balance provide typical examples, which also emphasize the central role of physical chemistry as a foundation for medical science. Biology occupies a special place, being inextricable from medical science and itself dependent upon physics, chemistry and mathematics. There is no reason that the foundation sciences cannot be learned in a PBL curriculum, or from problems in human health and disease; I would argue that this is the correct approach for health science students. But it may be unnecessarily complicated not to separate the levels of study. There should be a period when the main focus is on the foundation. Also, students who need this foundation, either before or after entering medical school, need access to appropriate resources, including people. Appropriate planning is therefore required.

Some consequences

The second issue is a more controversial idea that is, nevertheless, a natural development of what has already been presented. If it is important that physicians *understand* what they do (by criteria already presented), this is also important during subsequent professional life, not merely while they attend medical school. It follows that the basic science concepts that have utilitarian value to the undergraduate proceeding through a PBL curriculum would retain their utility, so that understanding does not disappear. These same concepts should be revisited in refresher courses and in continuing medical education, and not overlooked as part of the maintenance of competence.

The processes of change are incomplete

Finally, I would like to return to the central theme of this article, which is that the basic sciences, rather than being seen as tools central to the study of medicine, may not receive sufficient emphasis in a PBL curriculum. When Flexner ushered in the first revolution in medical education in North America, he believed strongly that the basic sciences were essential to medicine and to a sound training for physicians. The practice of medicine has ancient roots; the term "diagnosis" (knowledge through careful observation) was first used in 1681,[19] reflecting the age of these roots. The concept of "a disease" and its *diagnosis*, which is the focus of so much of what physicians do, can be alien to scientific thought. For example, the presence of a disease often implies a discontinuity from the healthy state, which has little meaning in scientific terms. To say that someone "has hypertension" emphasizes this discontinuity; the term may serve as convenient shorthand to indicate that the combined operation of a number of systems controlling the blood pressure is no longer appropriate for optimal longevity. But in all probability there is no discontinuity. There is a wide range of disturbances of the immune system, encompassing such diagnoses as rheumatoid arthritis, systemic lupus erythematosus, dermatomyositis, etc. Physicians devote considerable energy to deciding which name is most appropriate when a presentation is not "classic." It may be true that accumulated experience and research regarding the prognosis or future outlook for the patient may apply only to "classic presentations," but it is still unhelpful to apply a classic label to a non-classic case, because information applicable to the classic label may not apply.

Conclusion

Thus, the revolution of scientific medicine, which so profoundly influenced medical education in North America through the work of Flexner, remains incomplete. Until clinical medicine evolves to use a greater body of available scientific understanding of human biology than is currently the case, portions of this material will appear to lack utility. Descriptions of disease, and diagnoses that reflect concepts incompatible with modern biology, should be modified or replaced. Only with change such as this will the maximal potential for utility be realized in learning the scientific basis of medicine.

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