Cognition Before Curriculum: Rethinking the Integration of Basic Science and Clinical Learning

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Abstract

Purpose
Integrating basic science and clinical concepts in the undergraduate medical curriculum is an important challenge for medical education. The health professions education literature includes a variety of educational strategies for integrating basic science and clinical concepts at multiple levels of the curriculum. To date, assessment of this literature has been limited.

Method
In this critical narrative review, the authors analyzed literature published in the last 30 years (1982–2012) using a previously published integration framework. They included studies that documented approaches to integration at the level of programs, courses, or teaching sessions and that aimed to improve learning outcomes. The authors evaluated these studies for evidence of successful integration and to identify factors that contribute to integration.

Results
Several strategies at the program and course level are well described but poorly evaluated. Multiple factors contribute to successful learning, so identifying how interventions at these levels result in successful integration is difficult. Evidence from session-level interventions and experimental studies suggests that integration can be achieved if learning interventions attempt to link basic and clinical science in a causal relationship. These interventions attend to how learners connect different domains of knowledge and suggest that successful integration requires learners to build cognitive associations between basic and clinical science.

Conclusions
One way of understanding the integration of basic and clinical science is as a cognitive activity occurring within learners. This perspective suggests that learner-centered, content-focused, and session-level-oriented strategies can achieve cognitive integration.

Integrating the knowledge necessary for the practice of medicine is an enduring challenge for medical education.[1] In particular, incorporating the teaching of basic sciences with clinical skills training has been a concern since the Flexner Report (1910) characterized basic science training as a crucial component of medical education.[2] Following Flexner's report, most medical schools adopted the 2+2 curriculum in which the first two years of early foundational basic science education are separate from two later years of clinical training.[3,4]

Soon after the nearly ubiquitous adoption of this 2+2 curriculum format, medical educators observed that it failed to integrate both knowledge domains (basic science and clinical), leading to frequent calls for improved integration of basic science.[5] As evidenced by the number of commentaries,[6–8] program descriptions,[4] curriculum guidelines,[9] and calls to action[10–12] published since Flexner's report, this concern has not abated over time. Recent major education reports outline integration as a strategic priority for medical education,[13,14] suggesting that integration is not a solved problem.

A large body of literature has outlined educational strategies to integrate basic science at multiple levels of the curriculum. In our critical narrative review of this literature, we use an established analysis framework[15] to describe how medical educators have integrated basic and clinical science at the levels of programs, courses, and sessions. We have evaluated the methods and outcomes reported within the health professions education literature to discern whether or not basic science and clinical knowledge have been successfully "integrated" at each of these three levels.

Method

In late 2012, we searched databases (MEDLINE, Web of Science, and Google Scholar) for relevant literature including research studies, commentaries, program evaluations, program descriptions, and reviews that discussed methods for, examples of, and evidence supporting approaches to the integration of basic sciences and clinical science. Our primary analysis focused on literature published in the last 30 years (1982–2012) that articulated learning rationales, interventions, designs, and methods for achieving integration.[16] We focused our review on literature that aimed to improve learning outcomes or skills. Although literature specific to medical education was our target, we included articles from other health professions when relevant, because efforts at integrating basic and clinical science have been made for other disciplines. Further, some basic principles of integration may apply to all disciplines.[4,17]

To focus our analysis, we included only literature that discussed the integration of biomedical sciences such as anatomy, physiology, pharmacology, etc. We

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defined clinical knowledge broadly to include knowledge of disease features, diagnosis, patient behavior, and health promotion. We included studies discussing a wide range of clinical skills, but, as with clinical knowledge, we did not aim to be exhaustive.

We organized our selected articles using the framework proposed by Goldman and Schroth (2012).[15] This framework examines integration as a strategy for achieving curriculum goals at three levels: program, course, and session. We define *program* as the superstructure of the curriculum that organizes all the formal education activities. A *course* is a discrete component within the program focusing on specific units of knowledge, and a *session* encompasses the specific, day-to-day activities relevant to teaching a portion of a unit of knowledge. The framework purports to provide a comprehensive approach that focuses both on the macro level (logistical or organizational concerns) as well as on the micro level (educational concerns such as the cognitive aspects of learning). The framework anchors on previous efforts to systematically and empirically address integration.[1,13,18,19]

We evaluated each article at each of the three levels to identify the method or approach for integration, the support for the methods, and evidence for success of integration. Below we discuss the claims, the evidence, and the significant approaches for each level of the curriculum (we discuss any article that spoke to two or three levels of the framework at each level, as necessary).

Results

Integration at the program level

The program is the structure within which education occurs—that is, the formal curriculum plan.[15] Two very common methods of planning for integration at this level are horizontal integration and vertical integration.[20,21] Horizontal integration refers to connecting the learning of concepts across different content areas, such as pathology and pharmacology, within a program of study.[21] The focus is combining and connecting topics within concepts or themes and learning how different areas build on one another as the learning progresses. Vertical integration, on the other hand, is the connection between different disciplines or bodies of knowledge. Vertical integration is often a synonym for the integration of basic and clinical sciences.[21,22] Using the basic science of cellular biology in teaching diagnosis of immune disorders is an example of vertical integration. Another type of program-level integration, longitudinal integration or the integration of the entire medical school curriculum, is gaining increasing traction, partly in response to the limitations of the 2+2 approach for training medical students. This type of integration involves connecting early factual basic science knowledge with experiential clinical learning. Other areas of the curriculum can be longitudinally integrated as well; for example, one popular approach is integrating different specialties during clerkship. Program-level strategies that longitudinally, vertically, or horizontally integrate basic sciences are diverse.[22–24]

One innovative approach to program integration is to revisit basic sciences as students progress into clinical learning.[25] The back-to-basic-sciences clerkship model reintroduces basic science concepts when learning takes place in clinical situations.[26,27] This approach aims to increase the use of basic science in clinical problem solving.[26] Proponents argue that reintroducing basic sciences when students have acquired some clinical knowledge will enable them to see the applicability of basic science information.[28] However, there is reason to doubt that this strategy will be universally successful. First, transfer of knowledge from one context to another is almost ubiquitously poor.[29–31] Second, students in later stages of training are forming advanced schemas for clinical reasoning[32] and may not appreciate the relevance of basic science; it may prove more useful to implement experiential learning in the context of basic science earlier in training.[33] Further, given the extensive demands of clinical learning, students may perceive the review of basic science as additional cognitive load.[34]

A similar approach uses the basic sciences to guide the learning of different clinical concepts.[35] For example, clinical educators may use nutrition science to teach pathologies that affect diet and absorption.[36] Disruption to the nutritional needs of the patient is framed as a factor that explains a host of clinical problems including diseases of lifestyle, socioeconomic causes of poor health, and the changes in health that can lead to different nutritional needs. Students report that basic sciences are more relevant when taught through this approach.[16]

Another common approach to integration is to provide either more basic science throughout the curriculum[37–40] and/or to increase the proximity between basic science teaching and clinical teaching. The latter is often the default strategy that, like revisiting the basic sciences (described above), relies on the spontaneous transfer of knowledge by the learners by virtue of repetition.[41] Often coupled with proximity is the redeployment of teaching personnel. Several studies[42,43] have outlined attempts to employ clinical faculty to teach concepts early in the curriculum and/or efforts to invite basic scientists to teach or present in clinical settings. Although some of these efforts have shown some knowledge gain in clinical conceptual knowledge,[43] most of the work has focused on describing how integration is accomplished or what the perceptions of students are.[42] Other research has noted that the best practices in redeploying teaching personnel are unclear.[44]

A recurrent program-level strategy is to adopt a traditional or hybrid problem-based learning (PBL) curriculum. Several studies describe PBL as a means of integrating basic science and clinical teaching.[45–50] At first glance, PBL may be an intuitive platform for integration.[51,52] Learners extract knowledge from real-world problems, allowing a contextualized demonstration of how basic sciences and clinical presentations relate to one another. PBL-based curricula are, however, delivered in a variety of different ways[53] with variations in content, setting, and tutors[54]—all of which affect learning outcomes. Although students trained through PBL do not necessarily gain less basic science knowledge,[48] systematic reviews of knowledge outcomes in PBL curricula suggest that the results are equivalent to traditional curricula.[55,56]

The methods that integrate basic science in PBL can be equally applied to lecture or hybrid curricula. For example, an observational[57] study of Dutch medical schools compared students at different training levels who experienced a traditional, PBL, or teacher-driven integrated curriculum. The authors described the teacher-led integrated curriculum as integrating basic and clinical science by centering teaching of both domains around specific organ systems. Although the curriculum had some small-group learning, it generally consisted of lectures and other traditional learning activities. The study's investigators examined the students' ability to accurately diagnose a series of detailed clinical presentations described in text-based vignettes. They found that the students in the integrated curriculum outperformed the PBL-trained and traditionally trained students during early training (years 2–3) and, in later training (years 5–6), were still superior to the traditionally trained students and equivalent to PBL-trained students.[57] These findings provide some evidence for the value of such integrated teaching programs and hint that integration is not specifically tied to the delivery method of the program (i.e., PBL) but, rather, to the content. Another similar curriculum evaluation also suggests that content and assessment, not delivery, are the deciding factors for integration.[58] Regrettably, the specific activities of integration that benefit the development of clinical reasoning in students are not clear from these large studies, and confounding factors such as differences in ability and prior experience cannot be ruled out.

Overall, this confounding is a limitation of evaluating any program-level strategies: learning outcomes are influenced by a number of factors, making it difficult to assess the reasons for differences between programs.[59,60] Furthermore, the literature incompletely describes the specific steps taken to integrate basic sciences, and evaluation attempts often measure learner satisfaction or attitudes rather than actual learning or changes in practice.[35–37,42–47] Program-level research can rarely evaluate knowledge or skills in a comparative fashion and with appropriate controls. When such evaluations do occur, they often measure factual basic science knowledge,[26–28] and their findings offer little insight into a learner's capacity to apply basic science concepts to clinical reasoning.[61]

Integration at the course level

There are several methods and levels at which course-level integration can be achieved.[1] We focus on two common methods: contextualization of basic science concept teaching[62,63] and shared teaching.[64]

Contextualization is demonstrating the applicability of a basic science principle or concept in a clinical situation (e.g., Laplace's law describes fluid flow in the lungs). Contextualized teaching can be accomplished in multiple ways, including presenting examples of basic science concepts during clinical lectures or PBL cases, as well as simulated cases demonstrating how basic science is applied.[38,41,65,66] One such approach to contextualization, case-based teaching,[66–70] involves teaching basic science and clinical concepts in the context of patient management, which provides a more practical, applied setting for knowledge.[40,65]

Other attempts at using contextualization to integrate basic and clinical sciences at the course level[71–73] have involved, first, integrating the teaching of anatomy and physiology by demonstrating the relationship between structure and function. This integrated understanding of human biology is then used as a platform for scaffolding practical clinical experiences early on in clinical training.[73–76] Some programs have described using dissection,[77,78] simulation,[63,79–82] and other experiences within the anatomy practicum to further contextualize basic science knowledge.[83,84]

Arguably, learning principles support contextualizing basic science information as doing so provides a concrete exemplar of the basic science concept.[52] The concept is not an abstraction but, rather, demonstrably applicable to clinical knowledge. In addition, the clinical application is more relevant for the learners and likely more engaging.[68,69] However, contextualization may also make the clinical realm simply another context among others in which basic science principles can be applied. Instead of illustrating how a particular scientific concept is *useful in understanding the clinical problem*, the clinical problem becomes a demonstration of the concept in action. Although this is an effective strategy for *teaching basic science*,[52] it can be misdirected if the goal is to develop students' understanding of clinical concepts. For example, the principles of fluid flow can be presented in the context of asthma in order to illustrate the application of the principles to medicine. This approach places the emphasis on understanding fluid flow prior to understanding the clinical aspects of disorders. Learners are exposed to the basic science without the benefit of understanding why it is particularly important for understanding asthma. Contrary to expectation, learners may achieve a better understanding of the science without adequately relating the concept to clinical problems.[31] Early studies of PBL notably showed this unintended outcome in that learners made more explicit references to basic science when solving clinical problems but also made more conceptual errors compared with non-PBL controls.[85,86] Although contextualization is a promising strategy, it may require further refinement.

A personnel-based approach is the shared teaching model. Shared course teaching places basic scientists and clinicians together to teach a course either simultaneously or sequentially across learning sessions. The literature describes several shared teaching courses, but in-depth description and evaluation are still required.[41,87–89] This gap in the literature is partially due to the highly contextual factors that would contribute to the success or failure of this approach. These factors include the synergy of the teachers, the depth of content covered, early buy-in (or lack thereof) from teachers of all backgrounds, and the quality of the exchange between basic scientists and clinicians. Some authors describing shared teaching have also noted the challenges posed by traditional departmental structures in moving to an integrated or shared teaching model.[90,91] The path of least resistance for shared teaching is sequential delivery of basic science and clinical content that likely has minimal effect on integration. We believe that if teachers pay inadequate attention to linking knowledge, then shared teaching runs the risk of devolving into a miniature reflection of the traditional 2+2 formula. These challenges may prove difficult to surmount because basic scientists and clinical faculty may disagree on how much basic science should be taught[92] and given the evidence (in teaching evaluations)[93] suggesting that students may value clinical instructors more highly than basic scientists.

In theory, assessing the effectiveness of integration at the level of course should be easier than assessing program-level outcomes, as the learners are in a more controlled environment. However, as with programs, studies comparing integrated and nonintegrated courses are rare. Most commonly, integrated courses show an improved attitude towards the importance of basic sciences.[42,68–70] But learning outcome studies have been more equivocal. For example, a large systematic review of case-based teaching found that although students preferred this method and believed that it does lead to integration, their actual knowledge gains were not greater than those of their peers who experienced traditional learning methods.[94] When investigators evaluated the learning outcomes of single courses, they often did so in the absence of appropriate control groups.[63,72,73,78] And as with program-level efforts, course-level studies risk confounding because multiple factors, including informal learning outside the course, can contribute to knowledge gains.[95]

Integration at the session level

Session-level integration strategies are the specific micro-level activities carried out from day to day to teach content. Several experimental studies have looked at specific learning interventions that have been adopted to promote the integration of basic science and clinical knowledge. Much of this session-level evidence derives from highly controlled studies such as randomized controlled trials or simulations of education interventions.

One technique to achieve integration is presenting basic and clinical sciences in a causal network. A series of experimental studies[96–99] demonstrated that students who received causally integrated explanations of pathologies were better able to diagnose difficult clinical cases (described in vignettes) compared with students who were taught the textbook signs and symptoms of the pathologies. According to these studies, integration was achieved by creating a cause-and-effect story or narrative that linked features of physiology to clinical pathology. Students given integrated explanations had a twofold advantage at diagnosis after a one-week delay.[96–99] These studies provide some evidence that creating cause-and-effect relationships between physiology and pathology is an effective technique in improving diagnostic ability. Using a similar approach, Baghdady and colleagues[100] showed that integrating basic sciences in a causal manner in lectures was far superior to providing only evidence-based structured algorithms for diagnosis. When students were presented with the basic science explanations in an unintegrated fashion (i.e., removed from the causal story and presented separately), the benefit for diagnosis decreased significantly.[100] Causal integration is not just an aid for memory and retention.[101] Rather, the cause-and-effect relationship between the basic sciences (such as the physiology of upper motor neurons) and clinical features (such as the symptoms of stroke) created a framework within learners' minds that allowed them to organize the constellation of the features of a diagnosis.[102] This cognitive conceptual coherence is the advantage of integrated basic science teaching.

This integrated session or lesson approach has been tested with nonbiomedical sciences as well. Students who were taught respiratory exam interpretation using explanations that referenced physics had superior performance at diagnosing new cases compared with those who did not have the benefit of physics teaching.[103] Similar, conceptually grounded interventions have included reviewing anatomy[74] or physiology in the context of specific procedural skills or explaining the correlations[76] between physiology and clinical features in a practical context (e.g., bedside teaching).[104,105] These studies provide further evidence for the benefit of linking clinical concepts and the underlying basic science concepts in a causally related manner.

Although the highly controlled nature of these studies can limit external validity, the conceptual approach yields a generalizable, practical, and theoretically sound principle that can guide day-to-day teaching. Overall, integration of content at the session level seems to have a meaningful educational impact. This approach is also theoretically grounded in research that highlights the essential role of basic sciences in supporting clinical reasoning.[106] Encapsulation theory describes the relationship between basic sciences and clinical expertise in expert clinicians.[107] It posits that basic science knowledge becomes enfolded by clinical knowledge as expertise develops[108]; for example, experts collapse detailed explanations of clinical and basic science presentations into meaningful categories such as a diagnosis or description like "inflammation" or "sepsis." The mechanisms and implications of states such as inflammation are captured within the concept for the expert. This absorption or "encapsulation" of concepts from basic science leads to progressively more sophisticated schemas for clinical activity. These schemas may not explicitly rely on basic science knowledge; however, the basic science information remains a key organizational principle for understanding clinical knowledge. Experts retain and use this basic science knowledge as needed; a series of studies showed that experts tend to extract this basic science knowledge when they confront difficult or nonroutine problems.[109,110] These findings further support the idea that basic science is a platform for clinical reasoning. These studies validate a long held assumption that basic science knowledge forms a cognitive framework for anchoring clinical knowledge.[111] Given this evidence, integration of curricula should focus on efficiently and effectively promoting the cognitive meshing of content knowledge from basic and clinical science. This linking is likely achieved most effectively at the level at which students make direct contact with the content of the formal curriculum: the teaching sessions.

Discussion

The challenges associated with integrating basic science into medical curricula are well described in the health professions education literature. In response, attempts to integrate basic sciences have been made at the level of programs, courses, and teaching sessions. Several themes emerge from the literature on these efforts.

Although description is ample, evaluation for learning outcomes—especially evaluation against comparators or control groups—is scarce. This paucity is partly a result of integrating the basic and clinical sciences at the program and course levels, where outcomes are more difficult to evaluate. This complexity may also account for the largely absent consideration of sociocultural factors such as attitudes towards the importance of basic science (and basic scientists) as well as structural and economic resources that can impact the feasibility of integration.

Secondly, integration is often described in terms of the methods and techniques rather than in terms of actual learning (i.e., logistically and organizationally as opposed to knowledge or skill development). Horizontal and vertical integration are organization principles that create the space within the curriculum for the actual act of integrated teaching and learning to occur. Strategies such as PBL, back-to-basic-science clerkships, and shared teaching models create proximity between two knowledge domains and foster awareness in students. However, whether these logistical changes lead to active integration of basic sciences and clinical knowledge *by* the student is unclear. Too often, integration activities are carried out with the expectation that the organizational change made will automatically result in integration. This leads to *integration becoming an end in itself* instead of a means to improved learning.

What is "integration" anyway?

The first step in considering integration is to outline the purposes and value of integration in the curriculum. However, the literature reveals that integration is most often characterized by the methodology by which it is achieved: the rearrangement or alignment of components of the curriculum. Although "vertical" and "horizontal" are useful terms for describing the methods of integration, we argue that overreliance on terminology can obscure the purpose of integrating basic and clinical sciences. We propose that, foremost, integration of these domains of knowledge should emphasize the cognitive activity that occurs within the learner. Simply creating "integrated" curricula will not automatically create cognitive integration.

With this in mind, we suggest that the aim of integrating the basic and clinical sciences is to achieve a conceptual, cognitive connection between different types of knowledge.[102,111] The term "integration" refers to situations in which knowledge from different sources (basic science, clinical, factual, experiential, etc.) connect and interrelate[112] in a way that fosters understanding *and* performance of the professional activities of medicine (diagnosis, management, etc.). This definition is learner-centered and focuses on changes within the learner as a result of exposure to basic and clinical science. The evidence from studies of expert clinicians[110,111] suggests that these experts use basic science to organize clinical knowledge and skills into a coherent network of concepts which form the basis of clinical reasoning. Therefore, the best use of the basic sciences is as a tool for helping learners more effectively understand and organize clinical concepts. Integration should be understood as a cognitive function or operation that occurs within the learner as he or she links clinical concepts with basic science. Once this understanding is adopted, the focus should shift to examining how the learning context, particularly workplace environments, aid or hinder cognitive integration.

Recommendations for medical education research

Understanding integration as a cognitive act creates a different standard for evaluating integration efforts. If cognitive integration is the intended goal of integration, then the outcome measures for research should encompass not just satisfaction, attitudes, or even retention of basic science facts but also the transfer and application of basic science knowledge. Assessing factual basic science knowledge might prove useful in encouraging students to pay attention to basic science content; however, assessing how students use that basic science content in clinical reasoning or in the performance of a skill would provide valuable evidence for the effectiveness of a specific integration strategy.

Several interventions discussed in this report have yet to be formally evaluated for achieving cognitive integration. Future researchers could examine whether these integration strategies enable learners to adequately use basic science to understand clinical concepts. This research would, of course, require assessment tools—some of which are already available[113,114]—that specifically require learners to display an integrated understanding of clinical concepts. For example, instead of simply requiring a diagnosis of a simulated case, assessments could also require an explanation—that is, the *why*[113] and *how*—of a particular mechanism that underlies the diagnosis. Finally, although much of the literature focuses on the formal aspects of curricula relating to integration, the informal hidden curriculum's impact[95] on integration is yet to be exposed.

Recommendations for medical education practice

From a teaching perspective, the specific steps to achieve cognitive integration may differ from content area to content area. Still, reframing integration as a cognitive issue shifts focus away from the content to be taught and places emphasis, instead, on the learning interventions conducive to teaching the content. This shift requires that educators pay greater attention to organizing and supporting session-level teaching for integration. If integration is understood as a cognitive process, then the integration of *specific* information—via lecture slides, practice problems, evaluations, and various media (words, pictures, practical experiences, etc.)—must occur. Without greater focus and emphasis on how basic sciences apply at each moment of clinical learning, reorganizing courses and clerkships could be a futile exercise.

Achieving this more microscopic integration of basic sciences may be more difficult for curriculum planners than reorganizing teaching schedules or clerkships. Each session and its associated content will require careful review to ensure that the material creates explicit and discernable linkages for learners. Uniformly adopting best practice teaching strategies, coupled with faculty development, may be required. Curriculum planners must also attend to the hidden curriculum[95] and whether it rewards the acquisition of facts as opposed to true understanding. Relevant to this, the assessment[61] of integrated learning should reflect students' sophisticated understanding of how the basic sciences relate to clinical practice—not their ability to recall facts. Focusing on assessment will not only allow direct evaluation of student learning but also inform students that integration is an important goal that is formally valued by the curriculum.

We do not suggest that any of the strategies or techniques for integrating curricula that we found in the literature and reviewed herein are fundamentally ineffective. Indeed, our analysis revealed positive effects on learning associated with the various types of curriculum integration as well as improved attitudes to basic science. These effects should not be underestimated. Yet, despite these attempts at integration, more attention must be paid to how basic science is conceptually connected to clinical reasoning by learners. We argue for drawing on current knowledge from cognitive science to inform the way in which basic science content is delivered to learners. Viewing integration from this functional, learner-centered, cognitive perspective can positively contribute to curricular reform and help effectively train clinicians.

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