2014, 1–11, Early Online MEDICAL TEACHER

AMEE GUIDE

The integrated curriculum in medical education: AMEE Guide No. 96

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Abstract

The popularity of the term "integrated curriculum" has grown immensely in medical education over the last two decades, but what does this term mean and how do we go about its design, implementation, and evaluation? Definitions and application of the term vary greatly in the literature, spanning from the integration of content within a single lecture to the integration of a medical school's comprehensive curriculum. Taking into account the integrated curriculum's historic and evolving base of knowledge and theory, its support from many national medical education organizations, and the ever-increasing body of published examples, we deem it necessary to present a guide to review and promote further development of the integrated curriculum movement in medical education with an international perspective. We introduce the history and theory behind integration and provide theoretical models alongside published examples of common variations of an integrated curriculum. In addition, we identify three areas of particular need when developing an ideal integrated curriculum, leading us to propose the use of a new, clarified definition of "integrated curriculum", and offer a review of strategies to evaluate the impact of an integrated curriculum on the learner. This Guide is presented to assist educators in the design, implementation, and evaluation of a thoroughly integrated medical school curriculum.

Introduction

As national medical education organizations, post-graduate training programs, and employers place ever-increasing scrutiny on preparing medical school graduates for large volumes of clinical work, medical school curricula around the world have undergone a major evolution in recent years. The historic Flexner report, "Medical Education in the United States and Canada" (1910), set forth many of the standards by which medical educations is shaped today, including the traditional "2 + 2" curricular structure in which two years of basic science are followed by two years of clinical science. Despite a century of evolution of the fund of knowledge in basic and clinical sciences as well as advancements in teaching strategies, this curriculum format still persists in many medical schools around the world, yet is viewed as an inadequate system to prepare future physicians for twenty-first Century medicine (Cooke et al. 2006; Irby et al. 2010). The rapid rise of and subsequent demand for providers to have expertise in areas such as population health, health policy, healthcare delivery systems, and interdisciplinary care has demanded that medical graduates possess knowledge and skills beyond a thorough understanding of applied anatomy and pathophysiology (Maeshiro et al. 2010). The Australian Medical Council (AMC) organizes the requirements for medical school graduation into four domains; traditional domains – "science and scholarship" and "clinical practice" – are now matched in emphasis with more

Practice points

- The Integrated Curriculum is becoming an increasingly popular concept internationally.
- The goal of integration is to break down barriers between the basic and clinical sciences currently in place as a result of traditional curricular structures.
- Integration should promote retention of knowledge and acquisition of skills through repetitive and progressive development of concepts and their applications.
- We suggest three areas in need of improvement and clarification for successful integration: ensuring synchronous presentation of material, avoiding the tendency to diminish the importance of the basic sciences, and using unified definitions.
- Goals and methods to evaluate whether the goals have been met are infrequently reported, utilized, and understood, limiting sustained success and growth of integrated curricula.
- We propose a unified definition of integrated curriculum and clarify definitions of common, less-comprehensive integrative strategies including "integrated courses" and "integrated clerkships".

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ISSN 0142-159X print/ISSN 1466-187X online/14/000001–11 © 2014 Informa UK Ltd.
DOI: 10.3109/0142159X.2014.970998

modern domains of "health and society" and "professionalism and leadership" (AMC 2012). This demand for recent graduates to develop a knowledge base beyond traditional medical school content is one major barrier to improving medical education. Additional barriers such as time constraints on faculty can limit the ability of medical schools to undertake necessary and comprehensive changes in curricula.

The Carnegie Foundation for the Advancement of Teaching, who originally published the Flexner Report, has more recently suggested that "ossified curricular structures" and "archaic assessment practices" present continuing challenges for those interested in significant curricular reform (Cooke et al. 2006). The International Association of Medical Science Educators' review of 100 years of Flexner's influence proposed that modern curriculum alternatives exist, particularly the "integrated curriculum" model, which could better promote the retention of knowledge across the basic and applied sciences (Finnerty et al. 2010).

Beane (1977) first reviewed integrated curricula in the general education literature and the term soon thereafter appeared in medical education (Harden et al. 1984). McMaster University in Canada was one of the first to implement a progressive, trans-disciplinary curriculum structure across all years of its curriculum (the "McMaster approach"), which has been developed, revised, and copied over the past several decades (Neufeld et al. 1989). Designed to be repetitive yet progressive, the "integrated curriculum" has rapidly risen to popularity with the belief that breaking down the barrier between the basic and clinical sciences improves connections between these disciplines and enhances graduates' retention of knowledge and development of clinical skills. Reports of curricular integration are numerous in the literature and have increased significantly throughout the past two decades (Figure 1).

The popularity of the concept has spread globally – references in this Guide include work from North America, Europe, Asia, and Australia/New Zealand – and is supported by many national medical education organizations. The Liaison Committee on Medical Education (LCME), the body responsible for the accreditation of all US medical schools, recently renewed its licensing standards and included the requirement that a curriculum be "coherent and coordinated" and "integrated within and across the academic periods of study" (LCME 2013). Recommendations for integrated curriculum have also been published by the Association of American Medical Colleges (AAMC; Corbett & Whitcomb 2004), the General Medical Council in the United Kingdom (2010), the Association of Faculties of Medicine of Canada (2009), the Australian Medical Council (2012), and the Inquiry on Medical Education in Sweden (Lindgren 2013).

We have increasingly observed use of the term "integration" often serving as a buzzword rarely accompanied by productive directions or suggestions for its development, implementation, and evaluation. In addition, "integrated curriculum" is loosely defined in the literature, having been used to represent a number of distinct curricular innovations. These include:

- The integration of discrete topics within a course of study, such as a implementing ethics and clinical skills education into first-year courses (Brunger & Duke 2012) or palliative care education across all years (Radwany et al. 2011).
- Integrating once separate courses or clinical experiences into a single unit, including combining basic science courses (Schwartz et al. 1999; Klement et al. 2011), preclinical or clinical preparatory education (Drybye et al. 2011), or clinical education (Ogur et al. 2007).
- Integrating clinical exposure into earlier stages of medical education (Yu et al. 2009).

These are but a few examples loosely organized into categories; further review of the literature reveals a spectrum of novel curricular innovations with differing depths of integration. Without guiding principles or unified definitions,

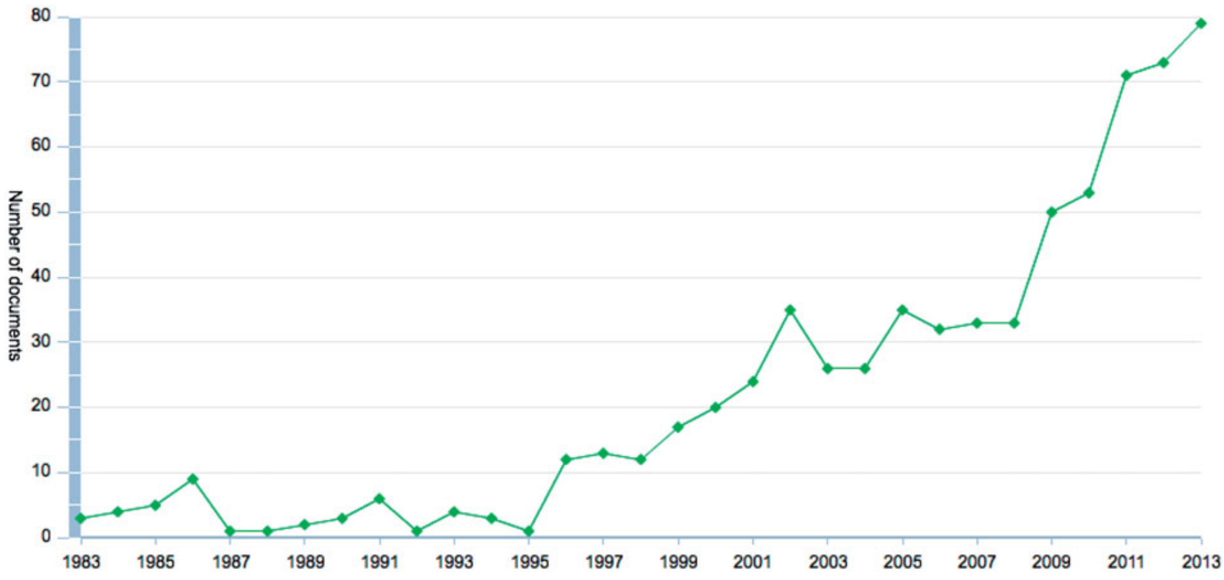

Figure 1. "Integrated curriculum" in the literature, 1983–2013. Published uses of "integrated curriculum", 1983–2013, in the Scopus database, Health Sciences and Life Sciences subject areas (Scopus 2014). A significant increase in the publications utilizing the term "integrated curriculum" can be seen, particularly within the last two decades.

integration becomes a concept and a process that means different things to professors, clinicians, students, and administrators, threatening to complicate the improvement and modernization of a curriculum. In this guide, theories and models of integration are reviewed, a clarified definition of integrated curriculum is proposed, and methods of assessment are highlighted. Organizing and uniting this information should allow educators to more easily move beyond pre-existing structures to create curricula that can promote retention and application of the vast and ever-increasing wealth of scientific and clinical knowledge.

Educational theories and models of integration

Several learning theories are relevant for this discussion of integration. First, adult learning theory, originally termed andragogy (Knowles 1980), identifies several general characteristics of adult learning. Of particular relevance to medical education is adult learners' interest in meaningful learning (Kaufman & Mann 2010) – learners are willing to invest time learning a topic only after they understand the topic's relevance. In medical education, basic science details are difficult to connect to clinical scenarios for beginning learners with limited or no clinical exposure; this challenge is overcome by linking basic science material to clinical problems, often through patient-based or case-based learning. Another relevant learning theory comes from the field of cognitive psychology and details how learners' organize knowledge: knowledge is most effective when the organization of that knowledge matches the way in which the knowledge is to be used (Ambrose et al. 2010). Thus, teaching medical students about basic science in the context of clinical examples and explicitly making connections among concepts through integrated presentation of material are two ways that integration can enhance long-term retention and deeper understanding. Finally, a third aspect of learning theory, also from cognitive psychology, concerns our understanding about transfer of learning. Using comparisons of clinical examples can help students identify deep features of basic science concepts that will help them elaborate on that knowledge as they progress into clinical education (National Research Council 2000). Educational theories are reviewed further in a separate AMEE Guide (Taylor & Hamdy 2013).

Education literature has long discussed curriculum design and the fundamental concepts and theories essential for implementation and revisions. In his book *Taxonomy of Educational Objectives: the Classification of Educational Goals*, Bloom et al. (1956) describes learning as having three domains: cognitive, psychomotor, and affective. These three domains might better be tailored to current formats of medical education if defined instead as knowledge, skills, and attitudes. Traditional fragmented curricula (in which basic science is followed by clinical education) develop the first domain, knowledge, in the classroom before allowing students the opportunity to develop the second domain, clinical skills; students are ideally exposed to the "attitudes" of medical practice (professionalism, ethics, etc.) throughout their education, either in the classroom or in practice. The real challenge of integration is how to transition from fragmented delivery to a synthesized delivery of these three domains throughout a medical curriculum.

Integration has come into favor with the hope that combining the delivery of information will increase efficiency and promote retention and ease of application. This is accomplished through repetitive discussion and progressive development of concepts. Educational models such "ICE" (Fostaty-Young & Wilson 2000) support this concept. Students are first introduced to foundational concepts (*ideas*), after which they connect or incorporate them with other learning (*connections*) to develop a fundamental conceptual framework. Learners then apply the concepts to real-life examples (*extensions*).

Integration as defined by Harden is "the organisation of teaching matter to interrelate or unify subjects frequently taught in separate academic courses or departments" (Harden et al. 1984). This organization can take place across a seemingly infinite spectrum of time periods or depths both within and among subjects. Harden has since developed a more concrete framework on which to map this spectrum integration by establishing discrete categories along an "integration ladder" (Harden 2000; Figure 2).

Designed to aid the planning process in implementing and evaluating medical curricula, the ladder presents curriculum integration as a continuum, with each progression of integration represented by a specific step on the ladder signifying integration with additional depth and extension of time and content. The final step, complete integration with "trans-disciplinary teaching" throughout all years of a curriculum, represents the ideal way in which medical school curricula would be organized to promote the learner's synthesis, application, and retention of material.

Curriculum models allow for visualization of current and intended curriculum formats using the two most basic components of a curriculum as reference points: time and the many scientific and clinical disciplines. Relevant models included here are horizontal integration, vertical integration, and spiral integration.

(1) *Horizontal integration* is defined as integration across disciplines but within a finite period of time. Examples of horizontal integration in the literature frequently describe the combination of once-separate courses, typically the basic sciences, into a unified, yearlong introductory course. One example, which combined first-year courses in anatomy, physiology, biochemistry, and neurobiology, took two years to design and implement but, by diminishing redundancy in content and examinations, students reported more time for independent study and greater satisfaction with their education (Klement et al. 2011). The McMaster approach represents horizontal integration by combining courses into units or "interdisciplinary blocks" before students begin their clinical learning (Figure 3).

(2) *Vertical integration* represents integration across time, attempting to improve education by disrupting the traditional barrier between the basic and clinical sciences. Examples include the "*Z*-shaped curriculum model"

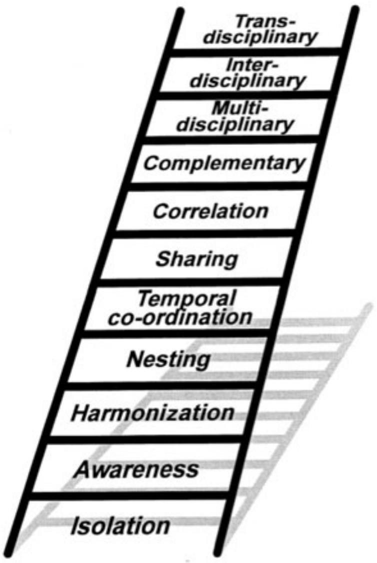

Figure 2. "The 11 steps on the integration ladder" (Harden 2000). The integration ladder suggests sequential steps for development of integrated curricula. Harden provides descriptions of each step on the ladder and makes clear distinctions between the progressive integration from one step to the next. Educators can easily compare their current or intended integrated curriculum projects to Harden's descriptions, which should assist in identifying precisely how "integrated" a project or curriculum truly is and what aspects of that project need to be further developed for a program to progress up the ladder.

- Step 1 is isolation, in which faculty organize their teaching without considering other subjects or disciplines.
- Step 2 is awareness, in which teachers of one subject are aware of what is covered elsewhere, but no explicit attempt is made to help students look at a subject in an integrated manner.
- Step 3 is harmonization, in which teachers communicate with each other about their courses and adapt their content accordingly.
- Step 4 is nesting, also called infusion, in which teachers target content from other courses within their own courses.
- Step 5 is temporal co-ordination, in which similar content is covered in parallel across courses.
- Step 6 is sharing or joint teaching, often conducted when there are common areas of content or there is a need to include new content in a curriculum.
- Step 7 is correlation, in which an integrated teaching session may be introduced in addition to subject-based teaching.
- Step 8 is complementary programming, often related to a theme or topic to which several disciplines can contribute.
- Step 9 is multi-disciplinary, in which themes are identified, sometimes related to an area in which practical decisions need to be made, other times when the subject matter transcends subject boundaries. These themes or problems are viewed through a multidisciplinary lens even though the disciplines maintain their own identity and understanding of the problem.
- Step 10 is inter-disciplinary, in which there is further development of the commonalities across disciplines.
- Step 11 is trans-disciplinary, in which the curriculum focuses on the learner's process of constructing meaning from information and experience. An example cited is the last two years of the Dundee curriculum (Harden et al. 1997), in which students focus their learning around 113 clinical problems or tasks to integrate their experience.

described by Wijnen-Meijer and others from the Netherlands (2009; Figure 4).

The *Z* model presents biomedical sciences and clinical cases "in parallel or in connection with one another". A student begins his or her education with mostly, but not entirely, basic science education and progresses through all years of a curriculum to finish with mostly, but not entirely, clinical science education. Benefits of this model are attributed to earlier clinical exposure, which increases student confidence in selecting a future specialty and improves perceived preparation for post-graduate training (Wijnen-Meijer et al. 2009, 2010).

(3) Spiral integration. Integration in its most ideal form might then represent a combination of both horizontal and vertical integration, uniting integration across time and across disciplines. Such a model has previously been described as "spiral integration", recently defined as a curriculum involving "*learning both sciences* [basic and clinical] *across both time and subject matter*" (Bandiera et al. 2013). This concept was originally introduced in the elementary education literature by Bruner, who proposed that teaching reading should involve an evolution of concepts over time. "What matters is that later teaching builds upon earlier reaction to literature, that it seek[s] to create an ever more explicit and mature understanding . . . . so too in science. Let the topics be developed and redeveloped in later grades" (Bruner 1960, p. 53–54). In this way, the learner is able to progress "to more complex versions" of the material originally introduced.

The spiral model was then applied to the medical curriculum in the UK (Harden et al. 1997; reviewed in Harden & Stamper 1999; Figure 5). In this model, foundational and clinical sciences interact equally throughout all phases of a curriculum, with common themes uniting the two as participants progress from students to physicians. This model was introduced in response to the GMC's call for "true integration of the course, both horizontal and vertical, using the term in the sense of interdisciplinary synthesis and not simply co-ordination or synchronization of departmentally based components" (GMC 1993). The benefits of this model are reported to be enhanced reinforcement of topics through a natural progression from simple to complex using a curriculum that "break[s] down the barriers and boundaries that have grown up between courses and departments" (Harden & Stamper 1999, p. 142). Themes such as clinical methods, ethics, and health promotion run throughout all years of the curriculum – bringing the model into a more modern era by emphasizing the broader concept of the clinical sciences deemed more relevant to physician success.

In addition to the GMC, other national medical education organizations support a spiral model by requiring integration throughout a course of study. The LCME requires that content "is coordinated and integrated within and across the academic periods of study, i.e., horizontal and vertical integration" (LCME 2013, p. 14) and the AMC similarly calls for "evidence of purposeful curriculum design which demonstrates horizontal and vertical integration and articulation with subsequent stages of training" (AMC 2012, p. 8).

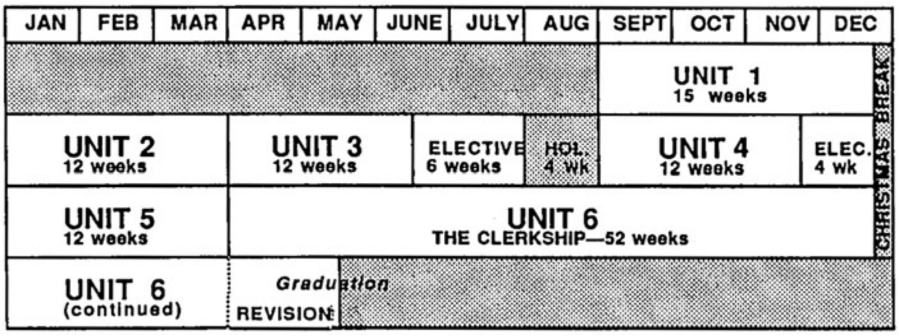

Figure 3. Horizontal integration: "The revised curriculum of the M.D. program at McMaster University" (reviewed in Neufeld et al. 1989). In this early representation of integrated curriculum from McMaster University (Hamilton, Ontario, Canada), horizontal integration is demonstrated through the combination of the pre-clinical basic science disciplines into units. The organization of material across disciplines over a finite time – not throughout the entire curriculum – represents horizontal integration.

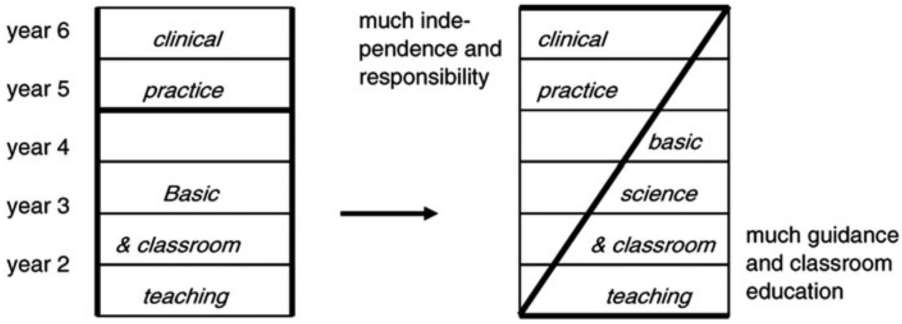

Figure 4. Vertical integration: "The traditional H-shaped medical curriculum replaced by a Z-shaped curriculum model" (Wijnen-Meijer et al. 2009). On the left, the H-shaped model represents the standard curriculum format in which basic science education precedes clinical education, with a distinct separation of the two. On the right, the Z-shaped model described by Wijnen-Meijer and others outlines a progressive introduction to clinical practice while maintaining a persistent basic science component throughout all years of a curriculum. This is an example of vertical integration.

Implementing integration

Creating an integrated curriculum can be time consuming and resource-intensive. No ideal "instruction manual" exists, but knowledge of theory and models along with review of the literature offer excellent starting points for educators. In addition, publications reviewing novel integrated curricular projects are often accompanied by discussion of the challenges and tips for revisions necessary for success (Schmidt 1998; Muller et al. 2008; Malik & Malik 2011; Ellaway et al. 2013).

One strategy that is likely to be of particular assistance to those revising a curriculum is mapping, reviewed by Harden in a separate AMEE Guide (Harden 2001). "Curriculum mapping is concerned with what is taught (the content, the areas of expertise addressed, and the learning outcomes), how it is taught (the learning resources, the learning opportunities), when it is taught (the timetable and the curriculum sequence) and the measures used to determine whether the student has achieved the expected learning outcomes (assessment)" (ibid. p.3). Mapping offers two key functions: (1) making the curriculum more transparent and (2) demonstrating links within the curriculum. Of particular relevance for this discussion are the links between expected learning outcomes, the curriculum content, and student assessment. Representing these relationships in a visible way helps ensure that learning outcomes are stated in terms related to the integration of concepts, that the content is delivered in a manner that requires integration, and that assessment methods require students to demonstrate this understanding. An example of concept mapping used in creating an integrated curriculum was published by Edmondson (1995), who utilized it for veterinary medicine education.

Additional strategies worth reviewing that are likely to aid educators prior to deconstructing and reconstructing a curriculum include mapping existing or conceptualized courses to Harden's ladder or the SPICES model of educational strategies (Harden et al. 1984). These models should serve as starting points for educators to visualize in what ways they may already be integrating and in what ways they could and perhaps should be integrating material and the delivery of that material.

In reviewing these strategies and the literature describing challenges in implementing an integrated curriculum, we have

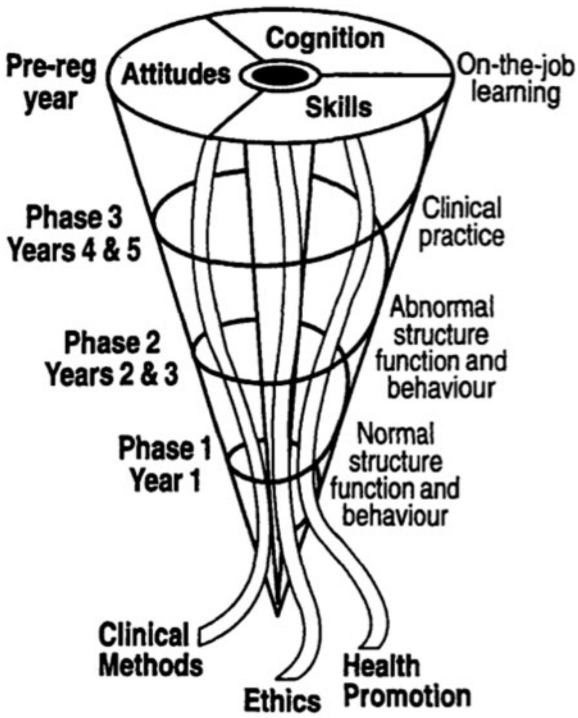

Figure 5. The spiral integrated curriculum model at the University of Dundee, Dundee, UK (Harden et al. 1997). This model illustrates a spiral curriculum in which the basic and clinical sciences are continually integrated as students' progress from learning the "normal" to the abnormal before the significant clinical portion of their education. At the top of the cone are three domains of learning – cognition (knowledge), skills, and attitudes – that are a focus of all levels of the spiral. Additional themes persist throughout all years – clinical methods, ethics, and health promotion – further emphasizing an evolution and subsequent broadening of physician education beyond the scope of this Guide.

identified three areas deemed in need of careful consideration during all phases of integration and review them here.

Ensuring synchronous presentation of material

Whether logistical changes lead to active integration of basic sciences and clinical knowledge by students is unclear; simply creating an integrated curriculum does not automatically create cognitive interaction. Similarly, simply coordinating content does not automatically establish integration. We have observed the most common form of published curricular integration in the literature utilizes increased exposure to the clinical learning environment. Rarely but perhaps more clearly referred to as "integrated clerkships", such experiences are shorter and occur earlier in a curriculum than traditional clerkships, typically as part of the basic science years. However, defining such clerkships as "integrated" can and at times has been narrow-sighted. Clerkships occurring during the basic science years without direct correlation to basic science course content do not reflect integration at all. Likewise, multi-disciplinary courses with objectives that are temporally coordinated but delivered as separate lectures by separate lecturers without connections to each other are merely coordinated courses, not integrated. A truly integrated early clerkship would demand that knowledge from the foundational sciences be applied in the clinical environment, and vice versa; creating proximity between two knowledge domains is simply not enough and sits squarely on the lowest rung of Harden's integration ladder.

Integrated courses must be carefully and collaboratively combined to be truly integrated. While thoughtful and precise curricular design is important, emphasis on the individuals delivering the integrated curriculum is an essential detail. Malik & Malik (2011), in a follow-up article to their original report on an integrated curriculum in Malaysia, offer 12 suggestions for a successful, step-wise approach toward total curricular integration. In addition to careful planning, they stress the creation of curriculum development groups with appropriate representation from both the foundational and applied sciences. For instance, a curriculum group for a particular clerkship module should appropriately include a majority of clinicians but must also emphasize participation from basic medical science educators. The authors also highlight the essential need that "lecturers refer to the contents of other teaching sessions and link and build on what was taught in the other disciplines" to ensure that a curriculum is integrated, not merely coordinated. Ideally, integrated sessions would be given synchronously as a collaboration between professors and/or clinicians individually representing the foundational and applied sciences or by a professor from one scientific realm (foundational or applied) with academic knowledge of the other realm. Such a combination of foundational science and applied science education and educators would finally yield the benefits of true integration to students. Additional benefits of trans-disciplinary cooperation among educators could be realized through the establishment of connections between clinicians and basic scientists with the potential to "produce spin-off effects in teaching and research" among professionals that otherwise might not have collaborated (Malik & Malik 2011, p. 99).

Preserving the basic sciences

The challenges of preparation for post-graduate medical practice demand additional applied learning, particularly with increasing emphasis on the expanding educational requirements for practice including ethics, professionalism, and other social sciences. The GMC calls for curricula to be "structured to provide a balance of learning opportunities and to integrate the learning of basic and clinical sciences" so students may "link theory and practice" (GMC 2009) but, with constraints on time and little additional direction for how to "structure" or "balance" an integrated basic science and clinical curriculum, we have observed that the pressure for increasing applied knowledge has resulted in a subsequent decrease in theoretical training.

The AAMC exposes this shift as a common flaw in the planning of supposedly integrated curricula, emphasizing "in the strongest possible terms of its conviction that there has been insufficient attention paid to the integration of basic science content into the third and fourth years of the curriculum" and that "the scientific basis of medicine should be integrated into coursework offered throughout the four years of the undergraduate medical education curriculum" (AAMC 2001). The group goes on to explain further challenges in preserving the basic sciences, pointing out that modernizing curricula is shifting the very definition of "basic science". While molecular, biochemical, and cellular mechanisms have been and will continue to be essential foundations for medical practice, adding objectives from scientific fields with increasing clinical relevance such as pharmacology, genomics and proteomics, and behavioral biology is essential to curricular modernization and can only benefit students. The LCME recently reiterated this broader concept of "basic sciences", requiring the inclusion of behavioral and socioeconomic subjects while maintaining biomedical science education to properly support contemporary scientific knowledge (LCME 2013). Bandiera, in tracking curriculum change and shifts in modern medical knowledge, offered revised terminology to reflect broader definitions of "basic science" and "clinical science", suggested their replacement with "foundational science" and "applied science", respectively (Bandiera et al. 2013). We support a transition to these updated terms to offer further clarity of the definitions within the discussion of integrated curricula.

True integration demands there never be an absence of the foundational science component at any stage of the medical school curriculum. Bruner (1960, p. 13) supports this notion, stating, "A curriculum as it develops should revisit these basic ideas repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them". With reports of successful and effective inclusion of the applied sciences in the years typically reserved for the foundational sciences (through "integrated clerkships" or similar), we must not forget that even our most senior students engaged in traditional clerkships should still view these as "integrated" learning opportunities; educators bear a significant responsibility in maintaining and reinforcing the fundamental sciences throughout all stages of the curriculum. Continually revisiting previous topics allows for a progression in which the student begins with a foundation of knowledge and gradually develops the capacity to add increasing levels of complexity and integration throughout the curriculum (Davis & Harden 2003). With so much emphasis on integrating basic science courses or extending clinical experiences earlier into a curriculum, extending basic science content into the clinical years has been a challenge and a major shortcoming of integrated curricula (Schmidt 1998). Examples of foundational science modules integrated successfully into the applied sciences are limited but include electronic modules in the Netherlands (Dubois & Franson 2009) and senior-level capstone courses reviewing and applying basic science in the United States (Spencer et al. 2008).

Using unified definitions

The integrated curriculum has so much to offer for students and educators but lacks clarity and unity in the literature. With careful consideration of theory and ideal models underpinning integration and its commonly published forms, a precise definition is necessary to aid in designing, implementing, and reviewing integrated curricula and integrated curricular units. Utilizing the spiral model as the ideal goal, we propose that "integrated curriculum" be defined as: *a fully synchronous, trans-disciplinary delivery of information between the foundational sciences and the applied sciences throughout all years of a medical school curriculum.*

Several effective curricular developments previously published as an "integrated curriculum" would no longer meet criteria under this new definition. Such models can easily be mapped to Harden's integration ladder, for they represent integrative components of a curriculum but not a fully integrated curriculum in themselves. A first year course uniting a variety of foundational science fields in a horizontal fashion could be consistently defined as an "integrated course", not an integrated curriculum (while we understand that this course may be described as having an internally integrated curriculum, we wish to emphasize the distinction between a course's curriculum and that of an entire medical school program for the sake of clarity in the literature). Similarly, clinical exposure encroaching earlier and earlier into the basic science years of medical education must be redefined. Such experiences should uniformly be defined as "integrated clerkships", but only if they are truly integrated into the basic science curriculum.

Assessing integration

Perhaps the most discouraging commonality observed in the literature on integrated curricula is the scarcity of published long-term effectiveness of such efforts. Useful retrospective reviews are available but are often limited to opinions based on group consensus or surveys (Lowitt 2002; Davis & Harden 2003; Brunger & Duke 2012). Outcomes trials exist despite the inherent challenges in establishing a truly controlled trial of a curriculum and often show at least non-inferiority if not objective benefits for the learner in an integrated setting (Van der Veken et al. 2009; Hirsh et al. 2012).

As with any major change in education, objective evaluation of its effectiveness is essential for its continuation and improvement. While it appears that an increasing number of reports are including outcomes data, our review of the literature has suggested that many aspiring curricular innovations are failing the test of time due to a simple failure as early as the planning and development stage: many groups report goals and expectations for their new curriculum but few describe methods of evaluation for gathering objective data to evaluate whether these goals are met. We hypothesize that this could be due to a lack of understanding of available standards of evaluation. The large literature review by Kulasegaram et al. (2013) suggests that " . . . 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". They further suggest that tools available for assessing students' use of basic science content in clinical reasoning are available but have not been used widely for evaluating integration strategies. Here, we present a brief review of published strategies that educators may apply to evaluate and improve their current or future integrated curricula.

Many examples of assessment and evaluation focus on providing students with validated tools allowing them to reflect on the foundational science concepts that led them to clinical decision-making. Reflection is an important skill for lifelong learning in general and for integrating concepts in particular. In describing strategies for integration as a curricular strategy, Goldman and Schroth (2012) suggest that posing specific reflection questions either before or after class sessions can enhance students' reflective abilities when faculty provide graded feedback and comments for additional reflection. Bierer and others describe an approach that combines multiple-choice questions (Self-Assessment Questions or SAQs) with essay questions (termed Concept Appraisals or CAPPs) that ask learners to provide a narrative interpretation of the mechanisms behind or reasons for the findings in a clinical scenario (Bierer et al. 2008,2009). Wood and colleagues describe a validation study of a Clinical Reasoning Exercise in which learners are asked to write a single paragraph explaining the mechanisms behind a particular patient problem (Wood et al. 2009); these assignments are then graded by independent raters to assess whether learners' performance on this exercise correlates with other measures. Williams and Klamen (2012) have described a Diagnostic Justification Exercise used with simulated patient encounters in which learners are asked to develop a differential diagnosis and explain their rationale for including the diseases/ conditions on that differential. Finally, an intervention study comparing students who received probability-based disease-oriented instruction with students who received conceptually based basic science instruction related to a particular disease showed that students in the basic science group were able to more accurately diagnose cases after a delay than were those in the probability-based group (Woods et al. 2005). The authors suggest that "... the basic science information, because of its conceptual coherence, was itself more memorable and that it also provided a means to reconstruct the features of individual disease categories after the initial symptom lists had been forgotten" (p. 111).

Concept maps represent another strategy for assessing integration of knowledge. McGaghie et al. (2000) demonstrated that students' maps regarding pulmonary physiology concepts became more coherent as a result of participating in an instructional unit on respiratory physiology, and the maps became more similar to maps developed by their instructors. In an earlier study (McGaghie et al. 1994), however, they showed that maps of experts differ significantly depending on the discipline of the expert (internist, anesthesiologist or physiologist), thus complicating the task of developing a "gold standard" by which to assess students' maps. In the spirit of integration, perhaps having groups of experts develop concept maps together would be helpful in both identifying important core concepts and in devising ways to assess students' integration of those concepts.

In a study of maps constructed by pediatric residents to represent their understanding of seizures, West et al. (2000) used a hierarchical scoring protocol that assessed concepts, linkages, hierarchies, cross links, and examples to derive an overall score. They demonstrated an increase in overall scores, cross-link scores, and concept link scores following an educational intervention. The Mind Map Assessment Rubric (MMAR), which adds dimensions of pictures and colors to hierarchical scoring of concept maps, has demonstrated inter-rater reliability in scoring of mind maps constructed by medical students (D'Antoni et al. 2009).

In a recent pilot study, Kumar et al. developed pathogenesis maps that were used to test students' understanding of key concepts. Experts first developed the "gold standard" map, which was then used to generate a list of key terms. Students in the intervention group then used these terms to construct their own maps and received feedback on the accuracy of their maps. Learners in the study group scored higher on quiz items related to content in the maps than had students who had not participated in the mind map intervention (Kumar et al. 2011). In another study, student response to the use of concept maps in Patient-Based Learning (PBL) tutorials (Veronese et al. 2013) indicated that students believed the exercise helped them integrate knowledge about the case and look more carefully at causality and connections among the concepts. Finally, Moni et al. (2005) used feedback from students to refine a scoring rubric that included: the content of the maps (e.g., were relevant concepts included), the logic and understanding demonstrated by the map, and the presentation of the map. While rubrics for grading concept maps are becoming more sophisticated, continued work is needed to further establish the validity and reliability of using them for testing purposes. Karpicke and Blunt (2011) demonstrated that retrieval practice, i.e., studying text, recalling as much as possible on a free recall test, studying again, and recalling again demonstrated better long-term recall on verbatim questions and inference questions than the elaborative strategy of concept mapping. They point out that it is not just memorization, but actively processing the information that has this effect.

Longer essays have also been suggested as a means for assessing students' integration of knowledge from a problem-based learning case. For example, Ferguson (2006) describes a method by which individual learners are asked to write a narrative about a case that they have studied in small groups over several weeks. The learner is asked to write, in the form of a conversation with a patient, how the patient's signs, symptoms and laboratory and imaging results relate to underlying mechanisms of disease, how the treatment recommendations are based on this understanding, and what the patient can expect from the disease and treatment. Writing the narrative in the form of a conversation accomplishes an additional purpose of practicing the skill of explaining difficult concepts in understandable terms.

In the University of Iowa (Iowa City, Iowa, USA) Carver College of Medicine's case-based learning curriculum, learners are required to do written reports of weekly learning issues. A significant component of those reports is the "application to case" section, which gives them practice and reinforcement in integrating information they learn from searching a topic by applying it to a particular patient scenario (Ferguson et al. 1997).

Progress tests have been used extensively in Europe to assess integration across courses. These tests are given periodically throughout the curriculum, and the items are intended to test cumulative knowledge across courses and vertically across the curriculum. A key component to constructing valid, high quality items for progress tests concerns ensuring their relevance in testing a new graduate's knowledge. A recent review (Wrigley et al. 2012) describes five criteria for improving relevance: "... items should test knowledge that is specific to the specialty of medicine, test ready knowledge (knowledge required as a prerequisite to function in a practical situation), be important knowledge which is required for the successful practice of medicine, have a practical relevance for the successful handling of high-prevalence or high-risk medical situations, and the knowledge should form the basis of one or more important concepts of the curriculum". Progress tests provide a unique opportunity for assessing growth in students' knowledge (Williams et al. 2011), and can provide data on which to base decisions about the curriculum as a whole as well as remediation strategies for the individual student. To accomplish these goals, however, requires significant investment of faculty and administrative time to develop item banks and ensure that exams remain relevant.

Swanson and Case (1997) provide examples of multiple-choice questions based on patient scenarios that test integration of basic science and clinical knowledge. In addition, they have suggested that open-book exams, especially those that require learners to apply scientific literature, may be especially helpful in assessing higher-order thinking skills such as integration of material. An additional benefit is that such exams drive faculty to write questions that cannot be answered by turning to a page in a book.

During clinical education, assessing learners' ability to apply basic science concepts through their diagnostic reasoning skills often occurs in the context of patient care. Bowen (2006) identifies learner skills in six areas: data acquisition and reporting, problem representation, generation of hypotheses, identifying appropriate diagnoses on the differential, having relevant experience for the case, and general presentation/organizational skills. She identifies clues that will uncover deficits in each of these areas and offers educational strategies for addressing each of them during clinical education. She further suggests that clinical teachers should "... encourage reading that promotes conceptualization rather than memorization ...." On a related note, "Learners should be encouraged to identify progressively broader and more complex issues, [and] explore them more deeply", thus reinforcing the notion of a spiral curriculum during the clinical years. One strategy for assessing this re-visiting would be incorporating basic science into online clinical cases and writing multiple choice items related to basic science concepts during clerkship examinations. The International Association of Medical Science Educators (IAMSE) and the MedU Consortium, a group of medical educators and students working together to develop innovative strategies and conduct educational research, are currently collaborating on a project called MedU Science to develop virtual patients that focus on causal mechanisms of disease and therapy (MedU Science 2014).

Conclusion

Curriculum renewal through integration within and across disciplines is occurring all over the world and has been promoted by many national medical education organizations. Despite and perhaps due to its popularity, the integrated curriculum has lacked significant clarity in the medical education literature and offers significant challenges to its designers. The Carnegie Foundation for the Advancement of Teaching, celebrating 100 years of the influence of the Flexner Report on medical education, accurately and succinctly reported that the difficulty in modernizing a curriculum is "not defining the appropriate content but rather incorporating it into the curriculum in a manner that emphasizes its importance relative to the traditional biomedical content and then finding and preparing faculty to teach this revised curriculum" (Cooke et al. 2006). Selecting content is only part of the battle; successfully integrating it across disciplines and across time to maximize student preparation is the true challenge.

Here, we have reviewed theory, models, and examples of integrated curricula, suggested that the spiral curriculum as an ideal model, identified and offered solutions to three frequent shortcomings of integration – ensuring synchronous presentation of material, avoiding the tendency to diminish the importance of the basic sciences, and using unified definitions – and outlined methods of evaluation to objectively track a curriculum's progress and effectiveness. We hope this guide will assist and encourage critical discussion among educators in all scientific disciplines as they develop, implement, and evaluate modern integrated curricula in medical schools around the world with the goal of equipping learners with the knowledge and skills necessary for the challenges of an exciting and constantly evolving field.

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Acknowledgements

Authors thank Mikael Wirén, MD, PhD, Professor of Surgery, Linköping University Hospital, Linköping, Sweden, and many

individuals at the Office for Student Affairs and Curriculum, University of Iowa Roy J. and Lucille A. Carver College of Medicine, Iowa City, Iowa.

Declaration of interest: The authors report no declarations of interest.

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