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Integrating the Basic and Clinical Sciences Throughout the Medical Curriculum: Contemplating the Why, When and How

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Abstract: A safe, effective clinician should have the ability to reason through any case they encounter — some of which may be unusual presentations or complex cases which may not fully match standard clinical practice guidelines. When faced with a situation that does not match a known pattern, a solid foundation in the underlying principles of the scientific basis of medicine would be needed to correctly reach the most probable diagnosis and choose the most appropriate treatment strategy. The ability to do this requires the clinician to be able to integrate relevant pieces of related knowledge from both the basic and clinical sciences. However, these two elements are often taught in a dissociated manner in medical school. This often results in students struggling to see connections between the two, and often perceiving the basic sciences as being not relevant to the practice of clinical medicine. The need for better integration of the curriculum has been recognized and many medical schools have attempted to implement an integrated curriculum to varying degrees. This article attempts to summarize the theoretical basis and available evidence supporting a fully integrated spiral curriculum as an effective model for medical curriculum development in order to train safe, effective clinicians. We also briefly discuss some challenges to this and some possible strategies to overcome them.

Keywords: Integrated curriculum; medical education; basic sciences

1. Introduction

The basis of a medical school curriculum is to produce doctors who are able to manage a variety of cases — from the simple to complex — safely and effectively. This seemingly simple aim, however, necessitates the blending of a wide range of information and skills in a complex balance; and a collective agreement of the best way of achieving this has never been reached. The lack of consensus on this is clearly illustrated by the wide range of medical curricula currently implemented in medical schools around the world.

The medical curriculum has evolved greatly over the years — possibly the clearest defining event in medical education remains the Flexner report in 1910. Abraham Flexner was commissioned by the Carnegie Foundation and the American Medical Association to assess medical education in Canada and America. At this time, medical education in America was based exclusively on an apprenticeship model, and he was impressed by the discipline-based method of teaching in Europe — especially in Germany — leading to the strong recommendation of his landmark report that the sciences played a fundamental role in the practice of medicine and should be similarly reflected in medical training. His report was largely what promoted movement toward an academic model of medical education; as opposed to the rather piecemeal and often exclusively apprenticeship model of medical training that preceded it.

Even today, at the core of their curricula, most medical schools worldwide follow the model largely based on Flexner's recommendations and have a curriculum of 2+2 (or 3) model with a clear division of the pre-clinical sciences or foundational sciences being taught in the first 2 years, and clinical sciences in the second half of the course. The basic sciences otherwise known as foundational or pre-clinical sciences are those that describe the biological mechanisms underpinning the function or dysfunction of the human body — such as physiology, anatomy, biochemistry and microbiology. The clinical sciences refer to information directly teaching the relationship between particular signs and symptoms with specific diseases, as well as how to diagnose and treat them[1]. One way of looking at this is that clinical sciences answer the question of 'what' while the basic sciences deal more with the 'how' and 'why' — all of which are needed to obtain a complete picture of a particular patient's condition.

Flexner's underlying philosophy in recommending the program structure he did came on the belief that having acquired a solid foundation of the basic sciences, the students would automatically apply it to cases seen in the clinical years. In the era before the Flexner report, medical training rested almost entirely on an apprenticeship model of simply learning by observing physicians at work with very limited and poorly specified theoretical foundations.

He strongly believed that physicians must deal with the complexities of the human body and apply biological concepts and principles in order to effectively analyze, assimilate, and solve novel and ill-structured patient problems[2].

Clearly, the legacy of his recommendations has resulted in a much more scientific and safe practice of medicine in large part due to generating wider acceptance of the idea that the basic sciences are fundamental in medical education, but there is still a lack of consensus on the most effective way in which to convey this knowledge to the students to maximize its potential to improve their clinical performance. We do know that this traditional method, while providing the students with the core theory has limited success in enabling cross over of the knowledge into the clinical years. Students have been described as feeling that the pre-clinical sciences are not relevant to patient care and simply a hurdle to be passed in order to enter clinical training[3–5]. It has also been demonstrated in several studies that students in the advanced years have a very poor recollection of the core sciences[6–9], with one study of retention of anatomy knowledge in a traditional curriculum reporting that the forgetting curve was almost identical to that of nonsense syllables[10].

An additional side effect of the discipline based teaching was the creation of segregated departments - while these enabled progress in medical science they also created a deep divide between the scientists and the clinicians[11]. This could in part be the reason a large number of senior clinicians felt that basic sciences were not relevant to the practice of medicine[12]. An incident related by Booth[13] describes how when Sir Henry Dale, the great physiologist and pharmacologist, first arrived to study medicine at St Bartholomew’s Hospital in 1900, a senior doctor, Samuel Gee, advised him to forget all the physiology he had learned at Cambridge as medicine was not a science but an empirical art. Paradoxically, this division and in some ways, the devaluation of biomedical science actually occurred as the ability to use new discoveries to rationalize clinical decision making was rapidly expanding[14]. This perception of basic sciences being disconnected and irrelevant to clinical science is untrue as studies have shown that even though many cases in clinical medicine are diagnosed through experience and pattern recognition, when confronted with a diagnostic challenge experienced clinicians do begin to explicitly rely on biomedical principles[15,16]. A longitudinal study analysing 3 decades of data also indicated that scores obtained by students in basic science evaluations were predictive of their future clinical competence evaluations after medical school[17] and other work has shown that level of retention of basic science correlates with clinical knowledge in final year students[6].Surveys among graduating students have also indicated that they would prefer greater degrees of integration between clinical and preclinical sciences to feel better equipped to practice[18].

2. Defining Integration and The Various Medical Curricula

There are several medical curriculum models that have been used over the years and in some form still form the basis of medical education today. These include the apprenticeship model[2], the discipline based model[19,20], outcome based model(21), hybrid spiral model[22] — all of which are summarized in Table 1.

Table 1. Summary of various medical curriculum models with their overall strengths and weaknesses

Curriculum model	General description	Strengths/weaknesses
Apprenticeship based curriculum model	• Practiced in the 1800s in America • Teaching by didactic lectures and shadowing mentors • No formal curriculum or textbooks	• No basic science teaching, only practical observations • Heavily dependent on rote memorization
Discipline-based curriculum	• Originated in Europe based on best practice • Teaching was by individual segregated departments who taught their own discipline related content independently of each other • 2 years of pre-clinical with no horizontal or vertical integration	• No horizontal or vertical integration • Teaching details of subjects through different departments in a repetitive, unrelated manner which had little apparent value to medical students
Organs system-based model	• Integrates basic sciences around a focus of single organ system • Basic science, pathophysiology of disease, and clinical sciences were integrated.	• Provided a more cohesive focus for the sciences • Students unable to use integrated knowledge to solve clinical problems in the clinical year
Problem based model	• Started by McMaster University in Canada • Structured around clinical problems and delivered through small group discussions • Emphasized active learning and student-centered learning. The students were given a clinical case as a problem and they had to use their prior knowledge to hypothesize and identify their learning needs	• Aids with knowledge retention • Gaps in knowledge base acquired by students • Resource intensive
Outcome based model	• Content of the curriculum, methods of teaching and learning, time allocation in different courses, and assessments are guided by the learning outcomes of the course	• Very teacher directed rather than student centered

Curriculum model	General description	Strengths/weaknesses
	• Graduating physicians are judged based on predefined competencies/outcomes.	
Clinical presentation curriculum	• Developed in University of Calgary, Canada • Teaching organized around the 120 ways a patient can present to a physician	• Teaches the basic science and clinical knowledge relevant to the various clinical presentations • Organizes knowledge to provide an approach to common clinical problems.
Hybrid with spiral design curriculum	• Basic science knowledge gained in earlier phase is revisited and used to build concepts of the next phase of the curriculum. • Basic sciences are taught even in the clinical clerkship phase. • Involves aspects of outcome-based approach, integrated learning organ-based approach, student-centered approach, and problem-based learning.	• Allows repetition with progression to enable reinforcement of content in authentic learning environment

Within the medical curricula, there has been a great deal of discussion about integration. However, the term 'integration' itself potentially has a wide range of meanings when used in the context of a medical curriculum. Among these, two definitions best fit the term as we are using it in this article: Shoemaker *et al*.[23] defined an integrated curriculum as "education that is organized in such a way that it cuts across subject-matter lines, bringing together various aspects of the curriculum into meaningful association to focus upon broad areas of study"; while Ron Harden defined integration as "the organisation of teaching matter to interrelate or unify subjects frequently taught in separate academic courses or departments"[24].

This integrated organization can potentially take place across a seemingly infinite spectrum of time periods or depths both within and among subjects although the two key terms used in this space are vertical and horizontal integration. Horizontal integration refers to teaching related disciplines such as anatomy, physiology and pharmacology concurrently; while vertical integration refers to integration of basic sciences with clinical subjects. This idea is illustrated in Figure 1.

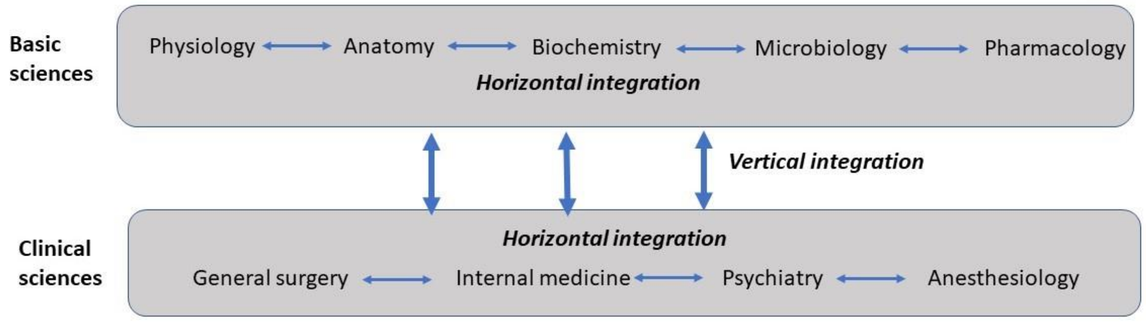

Figure 1. Illustrating the concept of vertical and horizontal integration within a medical curriculum.

3. Support for an Integrated Curriculum

3.1 Recommendations from Medical Education Bodies

The need to revisit and modify the Flexnerian, discipline-based way of the teaching of basic and clinical sciences to an integrated model has been one of the key items listed by several medical education consensus groups over the years. One strong voice for this is the Carnegie Foundation report "Educating Physicians: A Call for Reform of Medical School and Residency", whose recommendations include "strengthening connections between formal and experiential knowledge across the continuum of medical education, specifically by incorporating more clinical experiences earlier in medical school and providing more opportunities for knowledge building later in medical school and throughout residency."[25]

Other influential voices include the Edinburgh declaration from the World Federation for Medical Education in 1989, the Association of Faculties of Medicine of Canada's report entitled "The Future of Medical Education in Canada: A Collective Vision for MD Education " in 2009, and a document released by Association of American Medical Colleges and the Howard Hughes Medical Institute (AAMC–HHMI) in 2009. All of these advocates for the integration of basic and clinical sciences throughout the medical curriculum.

There is also support for this idea in some curriculum accreditation guidelines, for example, the Australian Medical Council require that a medical curriculum provide evidence of "both horizontal (within a programme segment or year) and vertical (across successive programme segments or years) integration of related subject matter." A document from the General Medical Council of the UK in 1993 entitled "Tomorrow's Doctors: Recommendations on Undergraduate Medical Education" — among other key reforms-recommended spreading out the basic sciences right across the course and introducing exposure to patients and their families from the beginning of the course[26] — in essence creating a spiral curriculum. The updated document in 2002 also includes the statement that

“The core curriculum must be the responsibility of clinicians, basic scientists and medical educationists working together to integrate their contributions and achieve a common purpose “and that medical graduates should ′ know about, understand and be able to apply and integrate the clinical, basic and behavioural and social sciences on which medical practice is based”[27].

To a large extent, from a purely theoretical perspective, there is in general a sense of agreement that greater degrees of integration between clinical and pre-clinical sciences would be helpful but a wide variety of factors make implementation of this in the wider curriculum challenging.

3.2 Educational Theory

Flexner’s original theory was that having acquired a significant amount of basic science knowledge in the preclinical years, this would then automatically allow students to apply this information to cases and clinical problems in the clinical years[28]; however the reality is that learning information out of context is tedious and retention is poor[5,29]. Looking at the traditional medical curriculum through the lens of the principles of adult learning theory or andragogy highlights several deficits that in the model with regard to effective learning and retention[30].

There are several elements of learning theory that support a move towards greater integration in the curriculum. Of particular relevance to medical education is adult learners’ interest in meaningful learning[31] — learners are only willing to invest time to learn a topic 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[32]. 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. Additionally, further learning theory with roots in cognitive psychology regarding transfer of learning also supports that making use of clinical examples in teaching basic science can help students identify deep features of basic science concepts that will help them elaborate on that knowledge as they progress into clinical education[5].

Herrington's principles of authentic learning state that meaningful learning takes place when course content is presented with a more authentic context, particularly when presented as a realistic problem preserving the complexity of the real-life setting[33]. Herrington also adds that to support this mode of learning, students should be able to access information resources as required, rather than have topics presented in a linear manner through weekly lectures and tutorials — this is an approach that would work perfectly in the clinical setting where students can review basic sciences linked to the cases they see in the wards having all the resources from the early years[34]. It has been noted by Woods and Mylopoulos[35] that "biomedical knowledge can help novices develop a coherent and stable mental representation of disease categories." Only after learners make new connections between their knowledge and specific clinical encounters, will they also be able make strong connections between clinical features and the knowledge stored in memory[36].

A spiral, integrated curriculum appears to be an ideal model that provides multiple timepoints within the curriculum where core ideas are repeated across a variety of time points and scenarios; and this repetition is a key strategy to enhance learning and engagement with ideas at a deeper level[37]. This model, which is designed to be repetitive yet progressive, has gained significant support as it seems to provide an achievable means of breaking down the barrier between the basic and clinical sciences; which would then improve connections between these disciplines, enhance retention of knowledge among medical graduates as well as boost the development of their clinical skills[38]. This will support the development of a feature that is seen in expert level clinical reasoning whereby the foundational sciences are so encapsulated within the clinical reasoning that the doctors are unaware of a divide in the two[35].

3.3 Studies on Various Forms of Integration in The Curriculum

Almost all medical schools have now, to some degree, begun to incorporate some clinical knowledge into the preclinical years, and a few have experimented with reintroducing the basic sciences during the clinical years. Since Case Western became the first school to launch an integrated curriculum in the 1950s(20), several studies have been done demonstrating various ways in which this system may aid learning. We summarize some of the published work on this in this section.

Duban *et al*.[5] had an opportunity to create an experimental parallel curriculum for teaching clinical skills in the 1st year of medical school in the University of New Mexico. This course was designed and run collaboratively by a mix of clinicians and basic scientists and taught the skills of history taking and physical examination together with the relevant basic sciences with the respective content experts working together. The students in the experimental arm attained the same basic science scores as the conventional curriculum, but scored much higher on clinical ($p<0.001$); and they also viewed basic sciences as relevant to clinical medicine as opposed to the conventional arm. The staff also reported gains — the clinical staff reported that they "understood in depth for the first time the diagnostic manoeuvres they had performed for years" while the basic scientists, by learning the physical examination along with the students, could better tailor their expertise into a useful resource for the students. Students also reported that the open, co-operative learning behaviour among teaching staff fostered a safe and engaging learning environment.

Goldszmidt[39] had an intervention group of students learning clinical skills of examination of the respiratory system in combination with explanations of how sounds transmit via the lung and chest wall and how this changes in normal and diseased states. The control group received the same information in a standard textbook format without the causal information. Questions related to the interpretation of physical exam findings served as the critical test items with the experimental group outperforming the control group on the critical test items. This indicates that learning the basic science underpinning the clinical findings can improve a student's memory for interpreting clinical details[39].

Woods[40] found that teaching clinical signs and symptoms together with the basic science 'story' explaining the clinical presentation improved students ability to recall the facts and make a diagnosis after a gap from the teaching session. Undergraduate medical student were taught a cluster of neurological or rheumatological diseases — one group learned them with basic science and the other with epidemiology. After 1 week, the group that did the basic science had much higher ability to recall and make a diagnosis a week after the class. Through an alternative method of teaching students to diagnose a series of artificial diseases with and without causal mechanisms; the students who learned a causal model were better able to retain their diagnostic performance over time[41].

Richards *et al*.[42] evaluated 3rd year students some of whom had undergone a PBL curriculum against others who had undergone traditional lecture-based curricula. The students who learned in a more integrated manner — ie the PBL curriculum — were more highly rated on all 4 parameters evaluated. Other studies have also demonstrated positive outcomes through PBL based integration of basic and clinical sciences[43]. Schmidt *et al*.[44] found that students who had undergone an integrated curriculum as opposed to a traditional curriculum were able to demonstrate superior diagnostic accuracy, leading them to suggest that integration between basic and clinical sciences and an emphasis on patient problems may be the critical factors that determine superior diagnostic performance. Nouns *et al*.[45] found that students were much more enthusiastic about basic sciences when they were taught in clinical context, but scores were equivalent for both integrated and conventional cohorts.

In terms of integrating basic sciences into the clinical years, one of the earliest reported attempts to have a "back to basic sciences" approach was described by Croen *et al*.[46] at the Albert Einstein School of medicine at Yeshiva University. An 8-week "return-to-the-basic-sciences" course was designed and run between the 3rd and 4th years of the medical program, meaning it came after a full year of clinical exposure. The course was designed to emphasize the importance of basic science in clinical medicine, unify various aspects of clinical teaching and expose students to some of the neglected or rapidly changing areas in medicine. A 5-year compilation of student feedback data from 1979 to 1984 indicated that the program successfully demonstrated the continuum of basic and clinical science knowledge and imparted scientific knowledge in an interesting way.

McGill University[47] attempted to reintroduce basic sciences in the final year of the course by allowing students to select from a range of 3 month long basic options. Student feedback indicated that they felt they had improved in their ability to integrate basic science knowledge into clinical as well as analyse and interpret clinical data. They also felt the course put the clinical knowledge gained into perspective and some also reported that it triggered their interest in research. The overall student opinion was that the return to basic sciences after clinical training was an excellent concept, and the students did not prefer to have the time for this basic science course allocated to the clinical departments ($p<0.001$)

University of Pittsburgh School of Medicine attempted a return to the basic sciences in the 4th year[48]. This was done in 1995 via the introduction of the Integrated Life Science (ILS) program. The ILS curriculum consists of a selection of courses, each 4 weeks long, that the students can choose to do at any point within their 4th year. It was mandatory to do at least one of the 7 offered. Each course was taught by both clinicians and basic scientists and was designed to be broad based and multidisciplinary while emphasizing core bench to bedside fundamentals; as well as providing opportunities for staff to interact and students to benefit from the inter-disciplinary interaction and exposure. The program met with very positive response, with the review committees evaluating the program opting to expand the program further.

Harvard introduced the Harvard Medical School-Cambridge Integrated Clerkship (HMS-CIC) where clinical students participate in weekly, case-based tutorials integrating instruction in the basic sciences with training to address the common and important issues in medicine. HMS-CIC students performed at least as well as traditional students in tests of content knowledge and skills, as measured by National Board of Medical Examiners (NBME) Subject Exams and the fourth-year Objective Structured Clinical Exam. They also scored higher on a year-end comprehensive clinical skills self-assessment examination, suggesting that they retained content knowledge better[49].

Dahlman *et al*.[50] described a formally implemented program integrating basic and clinical sciences within the advanced clinical years in Vanderbilt University School of Medicine. These "integrated science courses" were designed with collaborative inputs from clinical specialists and scientist to combine rigorous training in the foundational sciences with meaningful clinical experiences. More than 90% of students who had completed these courses agreed that the foundational sciences informed and enriched their clinical experiences and that the clinical experiences also enriched the foundational science learning; and 94% anticipated using the foundational science acquired in their future clinical work.

Overall, the general sense from students and educators is that are several positive points related to an integrated teaching of the basic and clinical sciences. It is a very complex endeavour to try to tease out definite data in terms of measuring outcomes of these curricular interventions, but in the reported studies that attempted quantitative measurements, the performance of those in the integrated curriculum was at a minimum non-inferior to — and in fact frequently exceeded- the traditional, with the students reporting a more enjoyable and meaningful learning experience

4. Discussion

Overall, there is a significant amount of data and theoretical foundations that support greater integration of the basic and clinical sciences in the medical curriculum: educational theory supports it; and perspectives of students and educators on feedback as well as quantitative data — where available — indicate that an integrated curriculum is well received and at a minimum non-inferior to the traditional curriculum. Consensus statements from several key medical education groups also strongly call for a move to a more integrated curriculum. However, despite the tremendous push for it, there are a limited number of schools who have moved to high degrees of integration, particularly as relates to integration in the clinical years.

Many schools have incorporated some clinical sciences in the pre-clinical years, but a very limited number have a formalized program of reintroducing the basic sciences in the clinical years. As of 2008, only 19% of U.S. medical schools and 24% of Canadian medical schools require basic science courses or experiences during the clinical years[48]. It has been noted that it is a greater challenge to bring basic sciences into the clinical years than vice versa with eight US medical schools having reported a lack of success in this endeavor[51]. These schools initiated several creative endeavours such as including basic scientists in ward rounds, adding basic science seminars and additional PBLs to 4th year but failed to meet their planned objectives due mainly to logistical and political reasons[51]. This perhaps, explains why in spite many calls for curricular revision, changes that have happened are not fundamental and widespread but rather in small isolated pockets of the curriculum[52].

One key reason proposed by several authors for the failure of attempts at integration is a lack of true involvement and engagement with the basic scientists[52,53]. At its core this may be traced back to the very clear division of the course into the pre-clinical and clinical years which then results in a disconnect between the teaching staff. It is known that there tends to be a certain mutual 'distrust' between scientists and clinicians with both sides teaching in siloes and little knowledge of what each side is teaching[54,55]. In fact, early attempts to integrate clinical sciences into the early years met with resistance from the scientists as they felt this would detract from and dilute the basic science teaching[46].

A challenge to the integration process is that, in an integrated curriculum, these basic science educators must recontextualize their content to mesh appropriately with its clinical application, despite not being trained as clinicians. Most biomedical PhD scientists have limited to no exposure to medical education or application during their own training. Yet to appropriately integrate basic science content with clinical application, these educators must develop an understanding of what scientific content is most relevant in a variety of specialties to appropriately focus their teaching for a medical audience[52,56]. It is important to note that these strategies can also benefit clinician educators as well as basic science educators in other health care curricula besides medicine[57].

This division needs to be addressed and active steps taken at an organizational level to break these barriers and create opportunities to bring the clinicians and scientists together. It has been noted that on a smaller scale, using friendships to build bridges between the two arms was unsuccessful in the long run[51], suggesting that in order to truly bring about change, there must be directives and clear cut initiatives from upper management. In order to create and sustain a truly integrated curriculum, the academic staff have to be deeply involved, enthusiastic and be able and willing to cooperate across departmental borders — aside from having a positive impact on education, this also has the potential to trigger research collaborations[43] particularly related to translational research. Understandably, the monumental nature of the task to try to create the changes needed to bring about a truly integrated curriculum are daunting to say the least, and may create a fair amount of complexities and tension among all involved. This may be at the core of explaining the lack of widespread change at a fundamental level of medical programs despite significant evidence for the benefits of an integrated curriculum.

5. Conclusion

On the whole, it seems clear that integration of the basic and clinical sciences seems to be a key element in developing a medical curriculum that fosters interest and competence in both clinical practice as well as research; although the appropriate balance of the sciences and the best integration model remain unclear. Innovations in integrated curriculum design have occurred internationally, but in most cases as small scale projects which do not change the curriculum at a fundamental level, a scenario that is unlikely to change unless solutions can be found to overcome the political and practical challenges of integrated curricula.

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References

1. de Bruin A, Schmidt H, Rikers R. The Role of Basic Science Knowledge and Clinical Knowledge in Diagnostic Reasoning: A Structural Equation Modeling Approach. Academic medicine: Journal of the Association of American Medical Colleges. 2005; 80: 765–773.

2. Finnerty EP, Chauvin S, Bonaminio G, Andrews M, Carroll RG, Pangaro LN. Flexner revisited: the role and value of the basic sciences in medical education. Acad Med. 2010; 85(2): 349–355.

3. Abdelrahman NuggedAlla MA, Mustafa Hegazy AA. Perception and Significance of Basic Sciences for Clinical Studies. International Journal of Human Anatomy. 2018; 1(2): 26–32.

4. Alam A. How do medical students in their clinical years perceive basic sciences courses at King Saud University? Ann Saudi Med. 2011; 31(t1): 58–61.

5. Duban S, Mennin S, Waterman R, *et al*. Teaching clinical skills to pre-clinical medical students: integration with basic science learning. Med Edu. 1982; 16(4): 183–187.

6. Lazić E, Dujmović J, Hren D. Retention of basic sciences knowledge at clinical years of medical curriculum. Croat Med J. 2006;47(6):882–887.

7. D'Eon MF. Knowledge loss of medical students on first year basic science courses at the university of Saskatchewan. BMC Med Edu. 2006; 6(1): 5.

8. Ling Y, Swanson DB, Holtzman K, Bucak SD. Retention of basic science information by senior medical students. Acad Med. 2008; 83(10 Suppl): S82–S85.

9. Watt ME. Retention of preclinical knowledge by clinical students. Med Educ. 1987; 21(2): 119–124.

10. Shulman LS. Cognitive learning and the educational process. J Med Educ. 1970; 45(11): 90–100.

11. Gupta K, Gill GS, Mahajan R. Introduction and implementation of early clinical exposure in undergraduate medical training to enhance learning. Int J Appl Basic Med Res. 2020; 10(3): 205–209.

12. Weatherall DJ. Science in the undergraduate curriculum during the 20th century. Med Educ. 2006; 40(3): 195–201.

13. Booth C. History of science in medicine. In: Teeling Smith G, C R, editors. Booth CC History of science in medicine In: TeelingSmith G, Roberts C, (editors). Science in Medicine: How Farhas it Advanced? L. London: Office of Health Economics; 1993. p. 11–22.

14. Brass EP. Basic biomedical sciences and the future of medical education: implications for internal medicine. J Gen Intern Med. 2009; 24(11): 1251–1254.

15. Joseph GM, Patel VL. Domain knowledge and hypothesis generation in diagnostic reasoning. Med Decis Making. 1990; 10(1): 31–46.

16. Woods NN, Brooks LR, Norman GR. The role of biomedical knowledge in diagnosis of difficult clinical cases. Adv Health Sci Educ Theory Pract. 2007; 12(4): 417–426.

17. Gonnella JS, Erdmann J, Hojat M. An empirical study of the predictive validity of number grades in medical school using 3 decades of longitudinal data: implications for a grading system. Med Edu. 2004; 38: 425–434.

18. Eyal L, Cohen R. Preparation for clinical practice: A survey of medical students' and graduates' perceptions of the effectiveness of their medical school curriculum. Med Teach. 2006; 28(6): e162–e170.

19. Dornhorst AC, Hunter A. Fallacies in medical education. Lancet. 1967; 2(7517): 666–667.

20. Papa F, Harasym P. Medical Curriculum Reform in North America, 1765 to the present: a cognitive science perspective. Academic medicine: journal of the Association of American Medical Colleges. 1999; 74: 154–164.

21. Harden RM, Crosby JR, Davis MH, Friedman M. AMEE Guide No. 14: Outcome-based education: Part 5-From competency to meta-competency: a model for the specification of learning outcomes. Med Teach. 1999; 21(6): 546–552.

22. Ganguly P, Yaqinuddin A, Al-Kattan W, Kemahli S, AlKattan K. Medical education dilemma: How can we best accommodate basic sciences in a curriculum for 21st century medical students? (1). Can J Physiol Pharmacol. 2019; 97(4): 293–296.

23. Shoemaker B. Integrative education: A curriculum for the twenty-first century. OSSC Bulletin. 1989; 33.

24. Harden RM, Sowden S, Dunn WR. Educational strategies in curriculum development: the SPICES model. Med Edu. 1984; 18(4): 284–297.

25. Cooke M, Irby DM, O'Brien BC. Educating physicians: A Call for Reform of Medical School and Residency. Jossey-Bass; 2010.

26. Committee GMCE. Tomorrow's doctors: Recommendations on undergraduate medical education. General Medical Council London; 1993.

27. Rubin P, Franchi-Christopher D. New edition of Tomorrow's Doctors. Med Teach. 2002; 24(4): 368–369.

28. Gwee MCE, Samarasekera D, Chay-Hoon T. Role of Basic Sciences in 21st Century Medical Education: An Asian Perspective. Med Sci Educ. 2006; 20(3).

29. Jason H. The Relevance of Medical Education to Medical Practice. JAMA. 1970; 212(12): 2092–2095.

30. Knowles M. The modern practice of adult education: From pedagogy to andragogy. Englewood Cliffs, NJ: Cambridge Adult Education; 1980.

31. Kaufman DM, Mann KV. Basic sciences in problem-based learning and conventional curricula: students' attitudes. Medical Education. 1997; 31(3): 177–180.

32. Ambrose S, Bridges M, DiPietro M, *et al*. How Learning Works: Seven Research-Based Principles for Smart Teaching: Jossey Bass; 2010.

33. Herrington J, Parker J, Boase-Jelinek D. Connected authentic learning: Reflection and intentional learning. Aust J Educ. 2014; 58: 23–35.

34. Herrington A, Herrington J. What is an Authentic Learning Environment? Authentic Learning Environments in Higher Education. 2008.

35. Woods NN. Science is fundamental: the role of biomedical knowledge in clinical reasoning. Med Educ. 2007; 41(12): 1173–1177.

36. Bowen JL. Educational Strategies to Promote Clinical Diagnostic Reasoning. N Engl J Med. 2006; 355(21): 2217–2225.

37. Bruner R. Repetition is the First Principle of All Learning. 2001.

38. Brauer DG, Ferguson KJ. The integrated curriculum in medical education: AMEE Guide No. 96. Med Teach. 2015; 37(4): 312–322.

39. Goldszmidt M, Minda JP, Devantier SL, Skye AL, Woods NN. Expanding the basic science debate: the role of physics knowledge in interpreting clinical findings. Adv Health Sci Educ Theory Pract. 2012; 17(4): 547–555.

40. Woods NN, Neville AJ, Levinson AJ, Howey EH, Oczkowski WJ, Norman GR. The value of basic science in clinical diagnosis. Acad Med. 2006; 81(10 Suppl): S124–S127.

41. Woods NN, Brooks LR, Norman GR. It all make sense: biomedical knowledge, causal connections and memory in the novice diagnostician. Adv Health Sci Educ Theory Pract. 2007; 12(4): 405–415.

42. Richards BF, Ober KP, Cariaga-Lo L, Camp MG, Philp J, McFarlane M, et al. Ratings of students' performances in a third-year internal medicine clerkship: a comparison between problem-based and lecture-based curricula. Acad Med. 1996; 71(2): 187–189.

43. Dahle LO, Brynhildsen J, Behrbohm Fallsberg M, Rundquist I, Hammar M. Pros and cons of vertical integration between clinical medicine and basic science within a problem-based undergraduate medical curriculum: examples and experiences from Linköping, Sweden. Med Teach. 2002; 24(3): 280–285.

44. Schmidt HG, Machiels-Bongaerts M, Hermans H, ten Cate TJ, Venekamp R, Boshuizen HP. The development of diagnostic competence: comparison of a problem-based, an integrated, and a conventional medical curriculum. Acad Med. 1996; 71(6): 658–664.

45. Nouns Z, Schauber S, Witt C, Kingreen H, Schüttpelz-Brauns K. Development of knowledge in basic sciences: a comparison of two medical curricula. Med Educ. 2012; 46(12): 1206–1214.

46. Croen LG, Lief PD, Frishman WH. Integrating basic science and clinical teaching for third-year medical students. Journal of medical education. 1986; 61(6): 444–453.

47. Patel VL, Dauphinee WD. Return to basic sciences after clinical experience in undergraduate medical training. Medical Education. 1984; 18(4): 244–248.

48. Spencer AL, Brosenitsch T, Levine AS, Kanter SL. Back to the basic sciences: an innovative approach to teaching senior medical students how best to integrate basic science and clinical medicine. Acad Med. 2008; 83(7): 662–669.

49. Ogur B, Hirsh D, Krupat E, Bor D. The Harvard Medical School-Cambridge Integrated Clerkship: An Innovative Model of Clinical Education. Acad Med. 2007; 82(4).

50. Dahlman KB, Weinger MB, Lomis KD, *et al*. Integrating Foundational Sciences in a Clinical Context in the Post-Clerkship Curriculum. Med Sci Educ. 2018; 28(1): 145–154.

51. Schmidt H. Integrating the teaching of basic sciences, clinical sciences, and biopsychosocial issues. Acad Med. 1998; 73(9 Suppl): S24–S31.

52. Hopkins R, Pratt D, Bowen JL, Regehr G. Integrating basic science without integrating basic scientists: Reconsidering the place of individual teachers in curriculum reform. Acad Med. 2015; 90(2): 149–153.

53. Dominguez I, Zumwalt AC. Integrating the basic sciences in medical curricula: focus on the basic scientists. Adv Physiol Educ. 2020; 44(2): 119–123.

54. Badyal D, Singh T. Teaching of the basic sciences in medicine: Changing trends. Natl Med J India. 2016; 28: 137–140.

55. Restifo LL, Phelan GR. The cultural divide: exploring communication barriers between scientists and clinicians. Dis Model Mech. 2011; 4(4): 423–426.

56. Haramati A. Educating the educators: A key to curricular integration. Acad Med. 2015; 90(2): 133–135.

57. Roberts DH, Schwartzstein RM, Weinberger SE. Career development for the clinician-educator. Optimizing impact and maximizing success. Ann Am Thorac Soc. 2014; 11(2): 254–259.