Facilitator: Douglas Larsen, MD
Discussant: Mahan Kulasegaram, PhD

Reconsidering Basic: Integrating Social and Behavioral Sciences to Support Learning

Zarah K. Chaudhary, MSc, Maria Mylopoulos, PhD, Rachael Barnett, Sanjeev Sockalingam, MD, MHPE, Michael Hawkins, MD, J. Darcy O'Brien, MD, and Nicole N. Woods, PhD

Abstract

Purpose

The integration of basic science mechanistic knowledge (pathophysiology and etiology) with clinical features (signs and symptoms) during learning leads to robust cognitive representations in novices and supports the development of clinical reasoning, including better diagnostic accuracy and later learning of related concepts. However, previous studies have used a limited scope of traditional biomedical sciences, including biochemistry, anatomy, and physiology. The use of extended forms of foundational knowledge, including behavioral and sociological sciences, that have been proposed to support learning and performance in complex health systems remains unexplored.

Method

Thirty-three first-year medical students from the University of Toronto MD Program participated in the study. The effect of integrated extended basic science (EBS) learning was compared with that of clinically focused instruction on an initial assessment of diagnosis using clinical vignettes and a "preparation for future learning" assessment (PFLA) to assess learning of new related content in medical psychiatry (co-occurring physical and mental health conditions).

Results

Both forms of instruction supported the development of diagnostic ability on initial assessment ($t[30] = 1.20$, $P = .24$). On the PFLA, integrated instruction of extended forms of basic science led to superior performance on assessing complex patients' health care needs ($t[30] = 2.70$, $P < .05$).

Conclusions

Similar to previous studies using integration of biomedical sciences, the integration of EBS can enhance later learning of new related concepts. These results have implications for curriculum design to support development of expert clinical reasoning.

Even as medical schools seek to innovate to respond to changes in the context of health care,[1–3] the development of clinical reasoning remains a foundational element of medical education. Studies of memory, learning, and decision making in students from across the health professions have demonstrated a key role for basic science knowledge in learning diagnostic reasoning.[4–9] Deliberate integration of basic science knowledge (pathophysiology and biochemistry) with clinical knowledge (signs and symptoms) has been found to support the development of clinical reasoning by enabling students to form more robust, conceptually coherent mental representations of diagnostic categories. Specifically, *cognitive integration*, the explicit linking of clinical manifestations and basic science mechanisms within the mind of the learner, has been shown to lead to better diagnostic accuracy, better performance on complex cases, and greater retention of learning over time.[5,6,10–15] Most important, compared with teaching clinical knowledge in isolation, instruction that integrates biomedical science has been shown to enhance later learning of new related concepts.[15] This pattern of performance suggests that integrated instruction both supports the effective application of knowledge during "routine" clinical reasoning and serves a critical role in developing clinical reasoning in novel, ambiguous, or complex situations that require new learning.[15] Taken together, this body of work suggests that integrated instruction of basic science content is a useful tool for developing essential clinical reasoning skills.[16]

While robust, research exploring the impact of integrated instruction has generally used a limited set of biomedical sciences as the basis for integration.[5,6,10,12,17,18] Traditionally, subjects such as biochemistry, anatomy, and physiology have been a focus of integration within medical curricula as they represent the core content areas that have been most readily aligned with the practice of medicine for more than 100 years.[19] Conversely, calls highlighting a mismatch between the changing needs of health systems and the way that health care professionals are currently trained have suggested that clinical work within current and future health systems requires that clinicians be proficient in both traditional biomedical basic sciences such as anatomy, physiology, and biochemistry and basic sciences that support learning and performance in complex health systems, including social determinants of health, behavioral processes, and knowledge of system structures and processes of care.[2,20] The expectation is that inclusion of these and other underemphasized forms of knowledge that we refer to as "extended" basic science will support an effective

Please see the end of this article for information about the authors.

Correspondence should be addressed to Zarah K. Chaudhary, The Wilson Centre, Toronto General Hospital, 200 Elizabeth St., Toronto, Ontario, Canada M5G 2C4; email: zarahkc@gmail.com.

Acad Med. 2019;94:S73–S78.
First published online July 30, 2019
doi: 10.1097/ACM.0000000000002907

approach to care in complex health systems and thus have significant implications for the training of future physicians.

While definitions of extended forms of basic science content have been proposed, the imperative to introduce this content into curricula has thus far been without any theoretical framework for implementation.[2,20,21] To ensure that educational curricula achieve their intended objectives and build capacity for learning and performance in complex health systems, it is not sufficient to simply add these new content areas (i.e., as discrete lectures or stand-alone additional sessions) into already brimming curricula without an understanding of their purpose or value.[19] Ideally, the integration of this new content into medical training would be done in a manner that fosters the development of cognitive integration, allowing learners to explicitly link knowledge of clinical signs and symptoms with mechanistic underpinnings of extended basic science (EBS). The anticipated value of this form of cognitive integration would be similar to the value associated with cognitive integration of other basic sciences. Done correctly, integration of EBS should help students develop coherent mental representations that serve as a basis for later learning. However, to date, the potential role for EBS in integrated instruction and preparation for later learning has not been explored.

The current study sought to determine whether the deliberate integration of EBS can support the development of diagnostic problem solving and later learning of new related concepts. We compared the effect of integrated instruction using EBS versus clinical-features-only instruction (clinically focused [CF]) on both an initial assessment (IA) of diagnostic problem solving using clinical vignettes and a "preparation for future learning" assessment (PFLA) that assessed later learning of novel, related content. Anticipating that integration of EBS would enable cognitive integration in a manner consistent with previous studies, we hypothesized that there would be no difference between the 2 instruction conditions on IA but that participants in the EBS group would outperform participants in the CF group on the PFLA.

Method

Design

The study employed a "double-transfer" design adapted from previous studies[22,23] (see Figure 1). In this design, students are first randomized to learn material under 1 of 2 possible instructional interventions and then complete an IA of knowledge acquired and knowledge to solve a clinical problem. Subsequently, all students are then given an opportunity to use this knowledge to learn new content (*transfer in*) and then to solve clinical problems pertaining to the new learning (*transfer out*) in the PFLA.[23,24] The experimental design is summarized in Figure 1. We assessed performance on both a diagnostic problem-solving task using clinical vignettes and PFLA using a clinical management framework.

Material development

We chose to use medical psychiatry content (co-occurring physical and mental health conditions) as the topic of study because of the inherent complexity in managing co-occurring conditions where multiple domains of knowledge must be incorporated using a biopsychosocial approach to care.

Initial learning instructional material. Learning materials were developed in consultation with 5 medical psychiatry content experts. Before case development, all experts were engaged in a modified Delphi process that generated consensus on (1) the most common categories of co-occurring physical and mental health disorders and their defining signs and symptoms and (2) basic science mechanisms to describe disorders' underlying etiology (i.e., explicit explanation of *why*) that predominantly included psychological, evolutionary biological, and sociological explanations with some traditional biomedical explanations in medical psychiatry (Table 1). Four of the 5 experts were then assigned a category and asked to develop preliminary narrative descriptions for each of the 2 learning conditions: (1) extended basic science causal learning and (2) clinically focused learning with no basic science mechanisms.

Other members of the research team (M.M., N.N.W., Z.K.C.) iteratively reviewed the case narratives to validate experimental differences between learning conditions. Edited cases were shared back with the experts to verify for accuracy of clinical content. Eight narratives were developed through this process (4 with extended basic science causal learning, 4 with clinically focused learning).

PFL learning instructional material. Two members of the research team (Z.K.C. and R.B.) used existing teaching materials from a framework to assess complex needs of patients (INTERMED framework[25]) to create PFL materials. The materials were then reviewed by content experts for their suitability for first-year medical students. The PFLA consisted of an existing INTERMED clinical instrument validated for use in assessing health services needs for complex patients in practice.[25,26] The format of this tool was adapted for use in the study, and all materials were reviewed by education scientists on the research team for compatibility with the experimental design (M.M. and N.N.W.).

Participants

Thirty-three first-year undergraduate medical students from the University of Toronto MD Program participated in this study. Participants were recruited using email advertisements. Respondents completed informed consent. This study was approved by the Health Sciences Research Ethics Board at the University of Toronto.

Data collection

Participants were randomly assigned to either the integrated EBS (N = 17) learning or the clinically focused (CF; N = 16)

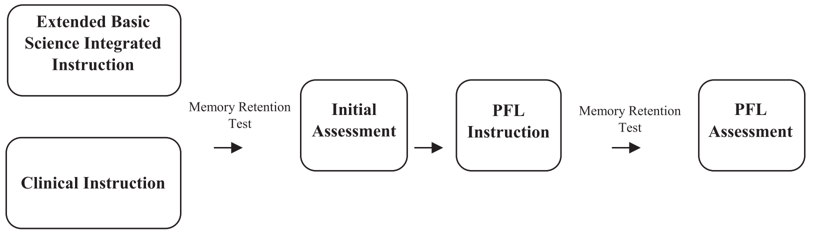

Figure 1 Study design. Adapted from Mylopoulos and Woods.[15] Abbreviation: PFL indicates preparation for future learning.

Table 1

Basic Science Causal Mechanisms for Medical Psychiatry

Category	Mechanism	Examples of explanations using extended forms of basic science
Psychological explanations	Attachment theory, response factors to illness like social conditioning and a person's cognitive repertoire of coping strategies	For asthma and anxiety, a student might learn that underlying fearful cognitions (mechanism) can give rise to catastrophic beliefs about respiratory symptoms that can be appraised to be unmanageable and in turn affect patients' sense of control and may result in less effective self-managing behaviors like smoking cessation.
Evolutionary biological explanations	Behavioral adaptability to one's environment with respect to illness outcomes such as harm avoidance or risk aversion	For schizophrenia and cardiovascular disease, a student might learn that accumulated adversity and chronic strains could affect development across the life span beginning with prenatal care and care received by parents throughout childhood. The lived experience of chronic strain negatively affects behavioral factors. For example, in some people, it can result in poor adaptations to stress, causing strain on the cardiovascular system and elevating the risk of heart disease.
Sociological explanations	Economic theory, socioeconomic vulnerability, downward drift hypothesis, social causation theory, health-system-level organization, and processes of care	A disproportionate number of patients with schizophrenia are observed to be in low socioeconomic class. Of several explanations, social causation theory would posit that low socioeconomic status (SES) causes increased risk for both schizophrenia and heart disease because socioeconomic deprivation increases the rate of death in severe mental illness.
Biomedical explanations	Inflammatory processes, neuronal and endocrine systems implicated in stress, genetic predispositions	Inflammation is suspected to be a central link in a bidirectional cycle of obesity and depression. Accumulating evidence suggests that depression often precedes higher levels of proinflammatory cytokines. Accumulating adipose tissue in obesity is also associated with a proinflammatory state. In some cases, then, adiposity can be a source of inflammation and cytokine signals in the brain that can affect neurotransmitter metabolism implicated in causing depression.

learning group condition. Students were individually scheduled to participate in the study. Participants completed all learning and testing materials independently on a desktop computer through a custom program designed using E-Prime 2.0 (Psychology Software Tools, Sharpsburg, Pennsylvania). The study consisted of 2 phases operationalized in a double-transfer design: the initial instruction and initial assessment (IA) followed by the PFLA.

Initial instruction. Participants were instructed to learn 4 categories of comorbid physical and mental health diagnoses: (1) Depression and Obesity, (2) Anxiety and Asthma, (3) Cancer and Depression, and (4) Schizophrenia and Cardiovascular Disease. Participants in the EBS condition learned the comorbidities with explanations of clinical features and basic science mechanisms to explain these features. Participants in the CF learning condition reviewed descriptions with the same defining clinical features and some epidemiological figures and associations (to balance content length between conditions) but without mechanistic explanations. Participants were allowed to take as much time as they required in learning this material. Immediately after instruction, all participants completed a memory test consisting of 14 multiple-choice questions to assess knowledge retention of the clinical features of comorbidities. A criterion score of 50% on the memory test was required for participants to continue in the experiment.

Initial assessment. Participants were presented with 14 clinical vignettes and were asked to respond with the most likely diagnosis or diagnoses for each case using free text. Responses were scored for diagnostic accuracy.

PFL instruction. In this second instructional phase, all participants learned new content information conceptually related to the initial instruction. The new material was identical for both groups and consisted of a 4-part framework to determine complex patients' health care needs, an abbreviated version of the INTERMED framework.[25] While the initial instruction material familiarized students with some of the most common comorbid disorders, this framework taught students how to manage this kind of complexity by defining the relevant concepts and variables. This framework emphasizes that biopsychosocial aspects of disease must be integrated to enable a coherent understanding of patients' context including the physical health system, psychological/behavioral health system, social system, and health system. Students learned that within each of these broad domains, 5 specific variables are used in practice to systematically assess health service needs. They learned a total of 20 variables that make up the INTERMED clinical assessment instrument (Chart 1). No time limit was imposed in learning the new material. Participants completed a memory test consisting of 20 multiple-choice questions to assess retention of the new material.

PFL assessment. The PFLA measured the participants' ability to apply the new content in the solution of novel problems. Students were presented with 3 elaborate complex patient scenarios (including comorbidity and ambiguous information built into the cases). Once they read each patient's scenario, the 20 variables from the INTERMED clinical instrument were presented sequentially. Students rated the variables they thought they needed to monitor or that required action. The responses for each of the 20 variables on this instrument consisted of a score from 0 (no need to act) to 3 (need for immediate attention). Student responses were scored by comparison with response consensus from 4 experts. A higher score indicates greater consistency with expert ratings, whereas a lower score indicates deviance from expert ratings. A mean score was calculated for each participant.

Data analyses

Individual participant scores were calculated for the memory quiz (initially and before PFLA), for diagnostic accuracy (IA), and for assessing patient

Chart 1

List of Variables Used to Assess Health Care Service Needs of Patients During PFLA[a]

Physical health domain	
Medications and treatments	0 ☐ 1 ☐ 2 ☐ 3 ☐
Chronicity	0 ☐ 1 ☐ 2 ☐ 3 ☐
Symptom severity and condition factors	0 ☐ 1 ☐ 2 ☐ 3 ☐
Diagnostic/therapeutic challenges	0 ☐ 1 ☐ 2 ☐ 3 ☐
Utilization factors	0 ☐ 1 ☐ 2 ☐ 3 ☐
Mental health domain	
Patient engagement/coping	0 ☐ 1 ☐ 2 ☐ 3 ☐
Adherence to treatment	0 ☐ 1 ☐ 2 ☐ 3 ☐
Mental health history	0 ☐ 1 ☐ 2 ☐ 3 ☐
Mental health symptoms	0 ☐ 1 ☐ 2 ☐ 3 ☐
Self-management and mental health risk	0 ☐ 1 ☐ 2 ☐ 3 ☐
Social system domain	
Residential stability/home environment	0 ☐ 1 ☐ 2 ☐ 3 ☐
Job/leisure	0 ☐ 1 ☐ 2 ☐ 3 ☐
Social support	0 ☐ 1 ☐ 2 ☐ 3 ☐
Social relationships	0 ☐ 1 ☐ 2 ☐ 3 ☐
Social support risk	0 ☐ 1 ☐ 2 ☐ 3 ☐
Health system domain	
Access to care	0 ☐ 1 ☐ 2 ☐ 3 ☐
Patient–team relationship/ experience with provider(s)	0 ☐ 1 ☐ 2 ☐ 3 ☐
Getting needed services	0 ☐ 1 ☐ 2 ☐ 3 ☐
Coordination of care	0 ☐ 1 ☐ 2 ☐ 3 ☐
Medical home/services risk	0 ☐ 1 ☐ 2 ☐ 3 ☐

Abbreviation: PFLA indicates a "preparation for future learning" assessment.
[a]Adapted from INTERMED.[25]

needs (PFL). We used independent-samples *t* tests to compare group means for these measures using SPSS Statistics 24 software (IBM, Armonk, New York).

Results

One student did not complete the learning phase and scored below 50% on the memory retention test. This students' data were therefore excluded from the statistical analyses (N = 32; EBS = 17, CF = 15). Total time to complete the experiment was not significantly different between the EBS (M = 77.19 minutes, SD = 26.4) and CF (M = 73.31 minutes, SD = 14.1) conditions ($t[28] = 0.533$, $P = .30$).

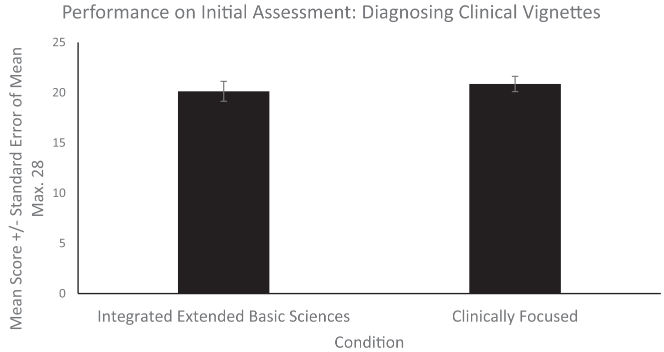

Figure 2 Initial assessment performance across extended basic science (EBS) and clinically focused (CF) conditions.

Initial learning

There was no difference between the EBS (M = 10.12 out of 14, SD = 1.41) and CF (M = 10.40 out of 14, SD = 1.40) groups ($t[30] = 0.567$, $P = .58$) on memory retention for the initial learning material. The 2 groups also had comparable performance when diagnosing clinical vignettes (max score = 28) on IA (EBS: [M = 20.13, SD = 3.96]; CF: [M = 20.86, SD = 2.85]; [$t(28) = 0.573$, $P = .56$]) as shown in Figure 2.

Preparation for future learning

There was no difference between groups on memory for PFL instruction material (max score = 20): EBS (M = 14.76 out of 20, SD = 2.63); CF (M = 15.67 out of 20, SD = 1.29); $t(30) = 1.203$, $P = .24$. On the PFLA, the EBS group outperformed the CF group in evaluating integrated health care needs using the 4-part framework. Similarly, in scoring the clinical significance of variables (max score = 180) used to address patient needs, the EBS group scored significantly higher than the CF group (EBS: M = 131.76, SD = 8.97; CF: M = 122.4, SD = 10.63); $t(30) = 2.70$, $P = .01$ (see Figure 3). A Cohen effect size value of d = 0.95 suggested a large effect.

Discussion

The aim of the current study was to determine the effect of an extended definition of "basic science" on cognitive integration and PFL. We found that integrated instruction of EBS with clinical signs and symptoms led to superior performance on a measure of PFL. This suggests that, similar to previous studies of integration of basic science, the integration of EBS can enhance clinical reasoning by providing essential mechanistic knowledge that supports cognitive integration.

Our results suggest that compared with clinically focused instruction, the integration of extended forms of basic science supports the development of a coherent mental representation that serves as a platform for new learning.[23] Consistent with other findings in the literature, the knowledge acquired during initial instruction shaped the way subsequent information was interpreted and used during the new learning phase. Critically, this benefit is not captured in conventional measures of near transfer (i.e., diagnosing

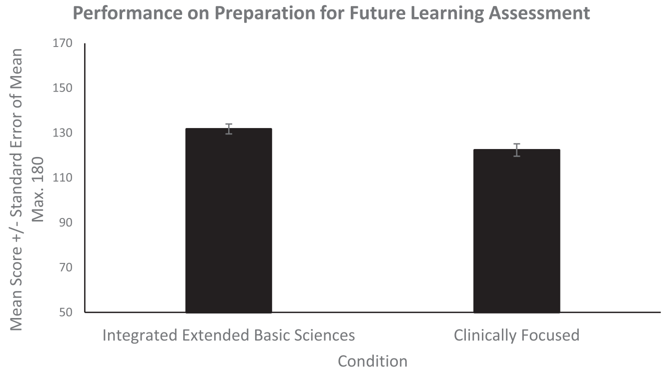

Figure 3 Preparation for future learning assessment performance across extended basic science (EBS) and clinically focused (CF) conditions.

clinical vignettes immediately after instruction) but is seen only when learners are assessed on their ability to learn new related content (i.e., through a PFLA).[23,27] This explains why the difference between the 2 learning conditions is not apparent on the IA. Consistent with other studies of PFL, the IA represents a traditional sequestered problem-solving approach, administered in close proximity to initial instruction and with no requirement to learn new information.[23,28] Performance on this type of task is generally not dependent on the coherence of learners' mental representation.

The results of this study extend the previous investigation of integrated instruction and PFL by challenging participants to learn new material related to treatment/management. Previous work has demonstrated that integrated instruction of diagnostic categories supported later learning of related diagnostic categories.[15] However, the PFL training and assessment materials used in that study closely mirrored those used during initial learning in both format and structure. In addition, while the content was new, diagnostic categories for PFL were related to the initial learning (neurological diseases in both instances). This meant that the overlap between initial and new learning may have facilitated performance on the PFLA for both groups. By introducing a management model in the PFL instruction phase and demonstrating that integrated instruction can support performance on distinctly separate learning and assessment tasks, the results of the current study are clearer evidence of the impact of integration even when there is no overlap between initial and new learning and the accompanying assessment tasks.

This study has a few methodological limitations typical in work of this nature. First, the study was conducted at a single institution and within a tightly controlled experimental session. Thus, the results are intended as a proof of concept and cannot be seen as a definitive evaluation of a specific teaching intervention in a real classroom. The limited time between initial instruction and the PFLA is consistent with other double-transfer studies but might be less than the typical delay between classroom sessions within real medical curricula.

Despite these limitations, our findings have significant implications for educational design in medicine and across the health professions. To date, the biomedical sciences have been our sole focus in the conceptualization and study of cognitive integration. This is the first study to experimentally explore the value of integration of extended forms of basic science on learning outcomes. The performance of students in the EBS learning condition suggests that other forms of knowledge, including behavioral and sociological sciences, can be incorporated within the cognitive representations of learners with effects similar to those demonstrated with traditional basic science. The current study, combined with the body of work on basic science integration,[5,6,10–15,17] suggests that curricula in the health professions should be designed to support the acquisition of a knowledge base that includes clear mechanistic underpinnings drawn from both traditional basic science and EBS. This broader integrated understanding may optimally foster the development of expert clinical reasoning.[16]

This study not only extends research on cognitive integration but also extends the literature regarding curricular development efforts for extended forms of basic science that may support the development of effective learning and performance in complex health systems.[2,20,21] It provides a theoretical framework for the meaningful integration of extended knowledge domains into curricula that are aligned with the goal of preparing for practice in a system with changing delivery models of care, increasing patient complexity, and changing population priorities.[29]

Acknowledgments: The authors wish to thank their medical psychiatry content experts for their help in designing and revising the study materials.

Funding/Support: This work was supported in part by the Medical Psychiatry Alliance, a collaborative health partnership of the University of Toronto, the Centre for Addiction and Mental Health, the Hospital for Sick Children, Trillium Health Partners, the Ontario Ministry of Health and Long-Term Care, and an anonymous donor.

Other disclosures: None reported.

Ethical Approval: This study was approved by the Health Sciences Research Ethics Board of the University of Toronto (ref no. 33049).

Z.K. Chaudhary is research associate, The Wilson Centre, University Health Network, and Faculty of Medicine, University of Toronto, Toronto, Ontario, Canada.

M. Mylopoulos is associate professor, Department of Pediatrics, and scientist and associate director, The Wilson Centre, Faculty of Medicine, University of Toronto, Toronto, Ontario, Canada.

R. Barnett is a medical student, MD Program, University of Toronto, Toronto, Ontario, Canada.

S. Sockalingam is professor, Department of Psychiatry, centre researcher, The Wilson Centre, University of Toronto, and vice president of education, Centre for Addiction and Mental Health, Toronto, Ontario, Canada.

M. Hawkins is clinical fellow, Medical Psychiatry Alliance, University of Toronto, Toronto, Ontario, Canada.

J.D. O'Brien is lecturer, Department of Psychiatry, University of Toronto, Toronto, Ontario, Canada.

N.N. Woods is associate professor, Department of Family and Community Medicine, and scientist, Wilson Centre and Centre of Ambulatory Care Education at Women's College Hospital, Faculty of Medicine, University of Toronto, Toronto, Ontario, Canada.

References

1 Asch DA, Rosin R. Innovation as discipline, not fad. N Engl J Med. 2015;373:592–594.
2 Lucey CR. Medical education: Part of the problem and part of the solution. JAMA Intern Med. 2013;173:1639–1643.
3 Kulasegaram K, Mylopoulos M, Tonin P, et al. The alignment imperative in curriculum renewal. Med Teach. 2018;40:443–448.

4 Woods NN, Brooks LR, Norman GR. The value of basic science in clinical diagnosis: Creating coherence among signs and symptoms. Med Educ. 2005;39:107–112.
5 Baghdady MT, Pharoah MJ, Regehr G, Lam EW, Woods NN. The role of basic sciences in diagnostic oral radiology. J Dent Educ. 2009;73:1187–1193.
6 Kulasegaram K, Manzone JC, Ku C, Skye A, Wadey V, Woods NN. Cause and effect: Testing a mechanism and method for the cognitive integration of basic science. Acad Med. 2015;90(11 suppl):S63–S69.
7 Kulasegaram KM, Chaudhary Z, Woods N, Dore K, Neville A, Norman G. Contexts, concepts and cognition: Principles for the transfer of basic science knowledge. Med Educ. 2017;51:184–195.
8 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;12:405–415.
9 Woods NN, Brooks LR, Norman GR. The role of biomedical knowledge in diagnosis of difficult clinical cases. Adv Health Sci Educ Theory Pract. 2007;12:417–426.
10 Woods NN. Science is fundamental: The role of biomedical knowledge in clinical reasoning. Med Educ. 2007;41:1173–1177.
11 Kulasegaram KM, Martimianakis MA, Mylopoulos M, Whitehead CR, Woods NN. Cognition before curriculum: Rethinking the integration of basic science and clinical learning. Acad Med. 2013;88:1578–1585.
12 Lisk K, Agur AM, Woods NN. Exploring cognitive integration of basic science and its effect on diagnostic reasoning in novices. Perspect Med Educ. 2016;5:147–153.
13 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.
14 Baghdady MT, Carnahan H, Lam EW, Woods NN. Integration of basic sciences and clinical sciences in oral radiology education for dental students. J Dent Educ. 2013;77:757–763.
15 Mylopoulos M, Woods N. Preparing medical students for future learning using basic science instruction. Med Educ. 2014;48:667–673.
16 Mylopoulos M, Woods NN. When I say … adaptive expertise. Med Educ. 2017;51:685–686.
17 de Bruin AB, Schmidt HG, Rikers RM. The role of basic science knowledge and clinical knowledge in diagnostic reasoning: A structural equation modeling approach. Acad Med. 2005;80:765–773.
18 Boshuizen HP, Schmidt HG. On the role of biomedical knowledge in clinical reasoning by experts, intermediates and novices. Cognit Sci. 1992;16:153–184.
19 Whitehead C. Scientist or science-stuffed? Discourses of science in North American medical education. Med Educ. 2013;47:26–32.
20 Gonzalo JD, Haidet P, Papp KK, et al. Educating for the 21st-century health care system: An interdependent framework of basic, clinical, and systems sciences. Acad Med. 2017;92:35–39.
21 Gonzalo JD, Dekhtyar M, Starr SR, et al. Health systems science curricula in undergraduate medical education: Identifying and defining a potential curricular framework. Acad Med. 2017;92:123–131.
22 Schwartz DL, Bransford JD. A time for telling. Cogn Instr. 1998;16:475–522.
23 Bransford JD, Schwartz DL. Chapter 3: Rethinking transfer: A simple proposal with multiple implications. Rev Res Educ. 1999;24:61–100.
24 Castillo JM, Park YS, Harris I, et al. A critical narrative review of transfer of basic science knowledge in health professions education. Med Educ. 2018;52:592–604.
25 Huyse FJ, Lyons JS, Stiefel FC, et al. "INTERMED": A method to assess health service needs. I. Development and reliability. Gen Hosp Psychiatry. 1999;21:39–48.
26 Stiefel FC, de Jonge P, Huyse FJ, et al. "INTERMED": A method to assess health service needs. II. Results on its validity and clinical use. Gen Hosp Psychiatry. 1999;21:49–56.
27 Rebello NS, Cui L, Bennett AG, Zollman DA, Ozimek DJ. Transfer of learning in problem solving in the context of mathematics and physics. In: Jonassen DH, ed. Learning to Solve Complex Scientific Problems. Mahwah, NJ: Lawrence Erlbaum; 2007:223–246.
28 Schwartz DL, Bransford JD, Sears D. Efficiency and innovation in transfer. In: Mestre JP, ed. Transfer of Learning From a Modern Multidisciplinary Perspective. Charlotte, NC: Information Age Publishing; 2005:1–51.
29 Frenk J, Chen L, Bhutta ZA, et al. Health professionals for a new century: Transforming education to strengthen health systems in an interdependent world. Lancet. 2010;376:1923–1958.