ACADEMIC
MEDICINE
Journal of the Association of American Medical Colleges

Uncomposed, edited manuscript published online ahead of print.

This published ahead-of-print manuscript is not the final version of this article, but it may be cited and shared publicly.

Author: Schmidt Henk G. PhD; Rotgans Jerome I. PhD; Rajalingam Preman PhD; Low-Beer Naomi MD

Title: Knowledge Reconsolidation: A Psychological Foundation for Team-Based Learning

DOI: 10.1097/ACM.0000000000002810

Academic Medicine

DOI: 10.1097/ACM.0000000000002810

Knowledge Reconsolidation: A Psychological Foundation for Team-Based Learning

Henk G. Schmidt, PhD, Jerome I. Rotgans, PhD, Preman Rajalingam, PhD, and Naomi Low-Beer, MD

H.G. Schmidt is professor of psychology, Department of Psychology, Erasmus University, Rotterdam, the Netherlands.

J.I. Rotgans is assistant professor of medical education, Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore.

P. Rajalingam is senior lecturer of medical education, Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore.

N. Low-Beer is professor and vice dean of education, Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore.

Correspondence should be addressed to Jerome I. Rotgans, Nanyang Technological University, Lee Kong Chian School of Medicine, 11 Mandalay Road, Singapore 308232; telephone: (+65) 9172 5213; e-mail: RotgansResearch@gmail.com.

Supplemental digital content for this article is available at http://links.lww.com/ACADMED/A686.

Funding/Support: None reported.

Other disclosures: None reported.

Ethical approval: Reported as not applicable.

Abstract

Although team-based learning is a popular instructional approach, little is known about its psychological foundation. In this Perspective, the authors propose a theoretical account of the psychological mechanisms through which team-based learning works. They suggest a knowledge reconsolidation hypothesis to explain how the distinct phases of team-based learning enable students to learn. Knowledge reconsolidation is the process whereby previously consolidated knowledge is retrieved from memory with the purpose of actively consolidating it again. Reconsolidation aims to preserve, strengthen, and adjust knowledge that is already stored in long-term memory. This process is generally considered an important reason why people who reactivate what they have previously learned many times develop knowledge structures that are extremely stable and easily retrieved.

The authors propose that four psychological mechanisms enable knowledge reconsolidation, each of which is tied to a district phase of team-based learning: retrieval practice, peer elaboration, feedback, and transfer of learning. Before a team-based learning session, students engage in independent, self-directed learning that is often followed by at least one night of sleep. The latter is known to facilitate synaptic consolidation in the brain. During the actual team-based learning session, students are first tested individually on what they learned, then they discuss the answers to the test with a small group of peers, ask remaining "burning questions" to the teacher, and finally engage in a number of application exercises.

This knowledge reconsolidation hypothesis may be considered a framework to guide future research into how team-based learning works and its outcomes.

Team-based learning (TBL) is the most recent addition to the collection of active-learning strategies proposed to improve student learning. These strategies include problem-based learning,[1] flipped classrooms,[2] and collaborative and cooperative learning.[3] TBL was developed in 1979 by Larry Michaelsen at the University of Central Missouri when increasing class sizes prevented him from teaching in the Socratic fashion.[4] The idea emerged for the first time in the medical education literature in 2005.[5] TBL was presented as a useful method to enable active student participation in larger classrooms.

In this Perspective, we will argue that TBL brings to the table more than initially meets the eye. We hypothesize that most of the class-based activities proposed in TBL encourage the reconsolidation of knowledge that students acquired previously.[6] This knowledge reconsolidation is considered vital to the long-term retention of knowledge. TBL is a newer approach to learning and instruction, hence little research regarding its effects on learning is available. Although we review much of the empirical literature on TBL here, we do not systematically review it. Ours is a first attempt to provide this new approach to teaching and learning with a tentative theoretical foundation. Such a theoretical foundation and its related practices in terms of measurement and interpretation may be helpful in guiding future research into TBL.

We first describe TBL in detail and review the studies conducted to assess its effectiveness. Subsequently we reinterpret the different class-based TBL activities in light of our knowledge reconsolidation hypothesis.

About TBL

According to Haidet and colleagues,[7] TBL typically consists of three distinct phases (see Chart 1). The first phase is the preparation phase, and it occurs before the actual TBL session. During the preparation phase, students study assigned learning resources to prepare themselves for the topics to be discussed during the TBL session. The second and third phases unfold during the TBL session itself.

The second phase is referred to as the readiness assurance phase and allows students to complete a test of their knowledge and understanding of the topic at hand, individually and within a small team, without referring to any learning resources. This test consists of multiple-choice questions that are first completed individually (Individual Readiness Assurance Test [iRAT]) then again with a team (Team Readiness Assurance Test [tRAT]). Teams are composed of five to seven students. They discuss each question, collaboratively decide on the best answer, and receive an immediate scoring of their answer. The scoring is typically done electronically and creates the opportunity for further discussion if the team answers incorrectly. At the end of the tRAT, teams spend time discussing the most difficult questions, look up answers to questions they were unsure of, and seek clarification from the teacher. The teacher provides confirmatory and corrective feedback to the students and if necessary further instruction.

The third and final phase is the application phase. During this phase, students are presented with case studies or vignettes that reflect significant real-world problems faced by professionals in the field. Within their teams, the students apply the course content they learned in the previous phases by proposing specific solutions to the problems presented and discussing their solutions with the class. The teacher calls on students to justify their solutions and critique each other's responses. At the end of this class discussion, the teacher typically presents best-practice solutions to the problems presented and summarizes the topics addressed during the session.

The above description represents the fundamental phases and processes in a typical TBL setting.[8] There can be some variation in the activities in each phase, depending on the institutional implementation of TBL. For instance, in some TBL settings, the post tRAT discussions are more formal activities that facilitate the generation of "burning questions" and, in other settings, students can appeal the scores they receive on the iRAT. There are also variations in how the teams are formed and how each component of TBL is graded.

TBL Research

Since the early 2000s, TBL has been gaining popularity in many educational institutions and programs. However, despite this popularity, relatively little empirical research has been conducted to explore its effectiveness and whether the underlying psychological assumptions can be empirically substantiated. The majority of published articles on TBL are descriptive accounts of how it was implemented at an institution or program,[9-11] how it was changed or modified when implemented ,[12] or students' satisfaction with it.[13]

A second body of research focuses on how effective TBL is in terms of learning outcomes when compared with other, more conventional, instructional approaches. These studies often used historical control groups in comparison or quasi-experimental setups.[14-17] Only very recently did the first empirical studies apply a more rigorous randomized experimental approach.[18-20] For instance, Bleske and colleagues[20] conducted a crossover study in which 30 students were exposed to three short TBL sessions and three short lectures on six therapeutic topics. Participants' knowledge was measured prior to and after the intervention. The results suggest that the TBL sessions resulted in significantly higher scores compared to those after the lectures. Thrall and colleagues[19] had different findings. They randomly assigned 115 psychiatry educators to TBL or a traditional lecture on attention-deficit hyperactivity disorder. Participants' knowledge was measured at the beginning, immediately after the intervention, and two months later. Comparison of the results immediately after the intervention revealed that the TBL group performed significantly better than the lecture group. However, the difference was small.

Furthermore, two months later, the group differences disappeared; no significant differences could be observed. In short, it is not entirely clear if TBL results in superior learning outcomes. When it comes to studies examining why TBL might work and which elements specifically might work, empirical data is limited. One exception is a study by Gopalan and colleagues[21] in which they investigated whether completing an iRAT before a tRAT benefited students in learning physiology. Their results suggest that completing an iRAT then a tRAT, rather than only completing the tRAT, resulted in superior performance. We will return to this study in more detail below.

Carbrey and colleagues[22] conducted a related study in which they explored whether the iRAT can be completed at home instead of in class. They applied a crossover design, in which first-year medical students were assigned to two conditions. In one condition, the iRAT and tRAT were conducted during scheduled class time. In the other, the students completed the iRAT at home and did not complete the tRAT. The authors then compared the effects of both conditions on students' scores on a 12-item physiology test. Their results suggest that there were no significant differences between the conditions as measured by the test scores. The authors propose their simplification (students complete just the iRAT at home) as a possible alternative to the conventional iRAT and tRAT approach.

Clearly, more studies are needed to understand how TBL works. However, to conduct such studies, we must develop hypotheses that potentially explain (1) how each component of TBL works and (2) how these components work together to maximize learning. In the remainder of this article, we describe our attempt to develop such hypotheses that describe the psychological mechanisms that may underlie each component of TBL.

Learning, Consolidation, and Reconsolidation of Knowledge

Contemporary theories of learning and of how memory works assume that simply learning new material is not enough to keep knowledge available for future use. Not only should students actively elaborate on what they learn, but knowledge also needs time to consolidate in memory.[23] The assumption is that knowledge is first stored biochemically in the brain. Protein synthesis plays a vital role in the early formation of new memories.[24] These early memories are unstable and can be easily disrupted. Think of an accident in which an individual suffers from a concussion. A concussion often leads to retrograde amnesia—the individual does not remember what happened in the last hours before the accident, probably because the protein synthesis process has been disrupted. Administering protein synthesis inhibitors after learning occurs has the same effect.[25]

A more permanent second phase of memory formation is synaptic consolidation in which memories take several hours to stabilize. Well-known is the fact that after a night of sleep our memory of the things we learned the previous day is much better.[26] (A third and final memory formation process is systems consolidation in which memories are moved from the hippocampal area to the cortex, where they become indestructible, although not necessarily retrievable. This process takes years.)

Memory reconsolidation is the process whereby previously consolidated knowledge is recalled for the purpose of actively consolidating it again.[6] Reconsolidation aims at preserving, strengthening, and adjusting knowledge that is already stored in long-term memory. It returns consolidated memories to a transient unstable state following their retrieval, from which they must again be stabilized to endure. This process is generally considered an important reason why people who reactivate what they have previously learned many times develop knowledge structures that are extremely stable and easily retrieved. Of course, our goal is that our students attain this state as a result of instruction.

TBL and Knowledge Reconsolidation

From our description above, it is easy to see how the three phases of memory formation—learning, consolidation, and reconsolidation of knowledge—occur during TBL. Students spend a number of hours learning new material independently, sleep (hopefully) eight hours to enable initial consolidation of what they learned, then they return to the classroom for reconsolidation exercises. In Table 1, we characterize these TBL activities in terms of the corresponding psychological constructs. These constructs together can be considered the psychological foundations of TBL.

Below, we review what is known about the effects of the four TBL reconsolidation activities—retrieval practice, peer elaboration, feedback, and transfer—on learning and memory.

Retrieval practice

Historically, tests were only used to assess what had been learned; that is, they were seen to assess learning and not as a mechanism of learning itself. We now know that this point of view is incorrect. Glover[27] demonstrated that students who take a test between their initial learning of the material and the final examination show higher levels of achievement compared with those who do not. He called this the "testing phenomenon"; when students were encouraged to retrieve their knowledge on an intermediate test, it seemed to strengthen their knowledge of the topic to an extent that they performed better on the final examination.

Teachers often encourage students to study in an elaborate manner. Karpicke and Blunt[28] were able to show that retrieval practice, or answering questions about a text, was even more effective than elaborate studying that included creating concept maps. The advantage of retrieval practice was observed with test questions that assessed students' comprehension and required them to make inferences. Even when students were required to produce a concept map as part of the final examination, those from the retrieval practice group did better than those from other groups. Retrieval practice encourages students to construct new routes in their memory to access the knowledge they learned thereby facilitating later retrieval of that knowledge. Roediger and Butler[29] summarize the benefits of retrieval practice as follows:

> First, retrieval practice often produces superior long-term retention relative to studying for an equivalent amount of time. Second, repeated testing is better than taking a single test. Third, testing with feedback leads to greater benefits than does testing without feedback, but even the latter procedure can be surprisingly effective. Fourth, … some lag between study and test is required for retrieval practice to provide a benefit. Fifth, the mnemonic benefits of retrieval practice are not limited to the learning of a specific response, but rather produce knowledge that can be transferred to different contexts.

In summary, the iRAT, which is presented to students the day after they have done their homework, can be considered a form of retrieval practice, aimed at strengthening the knowledge structures in the brain.

There is some evidence to support this hypothesis. Gopalan and colleagues,[21] in exploring the extent to which the iRAT contributes to learning in a physiology course, conducted a crossover study in which they investigated the effects of omitting the iRAT on tRAT scores, time to complete the tRAT, and scores on a unit exam. The results suggest that the groups that completed both the iRAT and tRAT had significantly higher tRAT scores and completed the tRAT significantly faster than the groups that took the tRAT alone. These outcomes suggest that retrieval practice has a positive effect—the students were better at answering the multiple-choice questions. However, no significant difference was observed on the unit exam scores. Clearly, further research is needed to establish whether the iRAT indeed constitutes the kind of retrieval practice that leads to superior learning.

Peer elaboration

Following the iRAT, the next step in TBL is the tRAT, a small-group discussion of the questions posed to students through the iRAT. Students go over each of the questions and discuss their answers. This small-group discussion has four purposes. First, it provides feedback to individual students regarding their performance on the iRAT. Above, we noted that, although learning from retrieval practice is enhanced even when no feedback is provided, accurate feedback is more helpful.[30] Second, the small-group discussion provides a means to elaborate on what is known and not yet known. Students can help each other understand difficult concepts or gain a new perspective on the knowledge processed during learning. Studies have demonstrated that group discussion is among the strongest activators of prior knowledge and helps in restructuring and embellishing students' knowledge.[31,32] Both students with little knowledge and those with much knowledge profit from group discussion, the latter most probably because explaining concepts to other students reinforces their own knowledge.[33] Third, the small-group discussion provides an opportunity for students to assess which issues are still unresolved and need to be shared with the class and teacher during the "burning questions" section of TBL. Fourth, working together in small groups encourages friendships and enables students to develop closer personal relationships with their teachers than they could in a larger classroom setting. Developing such relationships with peers and teachers is a safeguard against dropout.[34] In addition, since small groups provide peer pressure and natural deadlines for completing work, they encourage students not to postpone self-study.[35]

Feedback

Feedback is viewed as a potent mechanism to increase student learning,[36] and TBL provides multiple avenues for students to receive feedback. The first instance is during the tRAT discussion when teams receive immediate automated feedback on whether their answers are correct or not. This type of feedback on its own has a limited impact on learning. However, within a TBL team, it triggers further feedback from the other team members regarding the accuracy of the supporting arguments each student provided. Shute[37] classifies the types of feedback students receive into three categories: (1) knowledge of results, (2) knowledge of the correct response, and (3) elaborated feedback. A student receives the first two types of feedback within his or her team.

The teacher also has a role to play in providing feedback during TBL. His or her role is to provide elaborated feedback in response to the burning questions raised by the students following the feedback from their teams. Elaborated feedback has been shown to have a moderate to large positive effect on learning outcomes.[38] Such feedback should of course be accurate and timely. Feedback that is provided without considering the students' present needs and questions is useful only to a limited extent. Therefore, it is important that teachers confine themselves to responding only to the students' questions. As this feedback is driven by students' burning questions, the teacher is naturally constrained from providing feedback beyond what is necessary. An example of the specific burning questions that students ask can be found in Supplemental Digital Appendix 1 available at http://links.lww.com/ACADMED/A686.

Transfer

An important aim of instruction is to enable students to apply what they have learned in one context to another context. This process is generally referred to as the transfer of learning.[39] A distinction is often made between near transfer and far transfer (or high-road vs. low-road transfer). Near transfer refers to transfer between very similar contexts. For instance, if a student knows how to use an operating system on one computer, he or she is likely to be able to operate a different computer with the same operating system. Far transfer refers to transfer between two more remote contexts, for instance a student applying the second law of thermodynamics to market forces in a business context.

A fundamental assumption underlying the phenomenon of transfer is that it is enabled if one spots the similarities and differences in stimulus conditions between two contexts. If that happens, transfer is likely. However, in reality, transfer hardly happens; in particular, if far transfer is required, people often have difficulty seeing connections between two contexts.[40] There are, however, a few studies that suggest that, if the connections between two contexts are explicitly pointed out, students are more successful in transferring their knowledge.[41,42] According to Perkins and Salomon,[39] the lack of transfer of learning is not surprising since educational programs do not allow for transfer to be explored and practiced:

> Many learning situations offer practice only for a narrow range of examples and not enough practice to achieve significant automaticity, providing a poor basis for reflexive transfer. Mindful (high road) transfer requires active abstraction and exploration of possible connections. Many learning situations do not encourage such mental investments…

It can be argued that this concern does not apply to TBL since students have ample opportunities to apply what they have learned to different contexts during the application exercises. The application exercises are designed to help students form abstractions of what they have learned and apply their knowledge to different contexts by exploring similarities and differences. This process comes close to the idea of transfer.

Box 1 contains an example from a TBL cardiorespiratory course to elucidate this point. The course is taught to first-year medical students at a new medical school (Lee Kong Chian School of Medicine in Singapore) where the first two years are based on TBL. To respond to this case, a student would need to draw on various scientific topics that he or she has encountered previously, specifically human anatomy, lung mechanics, ventilation, and gas transport. The student, through discussions with peers and experts, would first have to understand which nerves are affected in a spinal cord injury at C6 as well as how this injury could result in a decrease in the patient's ability to take a deep breath and to exhale deeply. To answer the second question, the student would need to understand how a change in the patient's position coupled with the paralysis of the abdominal muscle will result in the diaphragm being less convex leading to a mechanically less advantageous position for contraction. Finally, to select the most appropriate ventilator setting, the student would have to calculate effective tidal volume by making realistic approximations and reasonable assumptions. These types of judgements are made routinely by clinicians in the course of their work. The intention of exposing first-year medical students to these types of problems is to better prepare them to make these judgements in the future.

Whether the above example is an exemplification of near or far transfer is not entirely clear since the line between the different types of transfer is blurred. It is however reasonable to assume that some form of transfer is taking place, considering that the student has ample opportunities to apply what he or she has learned. For instance, the Lee Kong Chian School of Medicine offers approximately 140 TBL sessions, of which two to four hours are devoted to application exercises like the example above.[43] A conservative estimate is that the students have 360 hours of practice to apply what they have learned to different contexts. This equates to nine working weeks devoted to practicing transfer under the guidance of subject matter experts. Although research findings are currently lacking, we expect some benefit coming out of this exposure to TBL application exercises.

Conclusion

In this article, we have tried to make the case for TBL as a means to strengthen knowledge reconsolidation. We believe that we have sufficiently argued that retrieval practice, peer elaboration, feedback, and transfer—the basic psychological mechanisms aimed at elaborating and improving on what is committed to memory—are all integral parts of TBL. Since this methodology is still in its early stages and research is lacking, it remains to be seen whether all the elements of TBL contribute to learning to the same extent. However, the systematic inclusion or exclusion of these elements, as pioneered by Gopalan and colleagues[21] and Carbrey and colleagues,[22] seems to be one promising approach to study how TBL works.

If we compare TBL with conventional approaches to higher education—simply defined as a series of lectures, a book, and an examination—we see that TBL invests more heavily in attempts to make knowledge accessible for future use. After all, the repeated reactivation of what has been learned previously serves that very purpose. One would therefore expect overall learning to be greater in TBL than in conventional approaches. The few studies that are available however do not yet fully support this hypothesis.[18-20]

TBL is not the only methodology that attempts to strengthen what students have learned. Most active-learning strategies, such as problem-based learning, the flipped classroom, inquiry learning, and interactive lectures, try to do the same. What makes TBL unique, however, is its emphasis on retrieval practice and the amount of time devoted to application exercises.

Why is it useful to frame TBL in terms of contemporary theories of learning and instruction? We argue that these theories, and their related practices in terms of measurement and interpretation, may guide appropriate research into TBL. Our knowledge reconsolidation hypothesis may just be the interpretation framework this new approach to learning and instruction needs to guide such research into how TBL works and its outcomes.

References

1. Schmidt HG, Rotgans JI, Yew EHJ. The process of problem-based learning: What works and why. Med Educ. 2011;45:792-806.

2. Hake RR. Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics. 1998;66:64-74.

3. Prince M. Does active learning work? A review of the research. Journal of Engineering Education. 2004;93:223-232.

4. Sibley J, Ostafichuk P. Getting Started with Team-Based Learning. Sterling, VA: Stylus Publishing, LLC; 2015.

5. Koles P, Nelson S, Stolfi A, Parmelee D, DeStephen D. Active learning in a year 2 pathology curriculum. Med Educ. 2005;39:1045-1055.

6. Lee JL. Memory reconsolidation mediates the strengthening of memories by additional learning. Nat Neurosci. 2008;11:1264-1266.

7. Haidet P, Levine RE, Parmelee DX, et al. Perspective: Guidelines for reporting team-based learning activities in the medical and health sciences education literature. Acad Med. 2012;87:292-299.

8. Michaelsen LK, Knight AB, Fink LD, eds. Team-Based Learning: A Transformative Use of Small Groups. Portsmouth, NH: Greenwood Publishing Group; 2002.

9. Huitt TW, Killins A, Brooks WS. Team-based learning in the gross anatomy laboratory improves academic performance and students' attitudes toward teamwork. Anat Sci Educ. 2015;8:95-103.

10. Travis LL, Hudson NW, Henricks-Lepp GM, Street WS, Weidenbenner J. Team-based learning improves course outcomes in introductory psychology. Teach Psychol. 2016;43:99-107.

11. Zgheib NK, Simaan JA, Sabra R. Using team-based learning to teach pharmacology to second year medical students improves student performance. Med Teach. 2010;32:130-135.

12. Davidson L. Educational Innovation in an Undergraduate Medical Course: Implementation of a Blended e-learning, Team-Based Learning Model [dissertation]. Ontario, Canada: Queen’s University; 2009.

13. Vasan NS, DeFouw DO, Compton S. A survey of student perceptions of team-based learning in anatomy curriculum: Favorable views unrelated to grades. Anat Sci Educ. 2009;2:150-155.

14. Chen M, Ni C, Hu Y, et al. Meta-analysis on the effectiveness of team-based learning on medical education in China. BMC Med Educ. 2018;18:77.

15. Emke AR, Butler AC, Larsen DP. Effects of team-based learning on short-term and long-term retention of factual knowledge. Med Teach. 2016;38:306-311.

16. Fatmi M, Hartling L, Hillier T, Campbell S, Oswald AE. The effectiveness of team-based learning on learning outcomes in health professions education: BEME Guide No. 30. Med Teach. 2013;35:e1608-e1624.

17. Bleske BE, Remington TL, Wells TD, et al. Team-based learning to improve learning outcomes in a therapeutics course sequence. Am J Pharm Educ. 2014;78:5.

18. Thomas PA, Bowen CW. A controlled trial of team-based learning in an ambulatory medicine clerkship for medical students. Teach Learn Med. 2011;23:31-36.

19. Thrall GC, Coverdale JH, Benjamin S, Wiggins A, Lane CJ, Pato MT. A randomized controlled trial of team-based learning versus lectures with break-out groups on knowledge retention. Acad Psych. 2016;40:755-760.

20. Bleske BE, Remington TL, Wells TD, et al. A randomized crossover comparison of team-based learning and lecture format on learning outcomes. Am J Pharm Educ. 2016;80:5.

21. Gopalan C, Fox DJ, Gaebelein CJ. Effect of an individual readiness assurance test on a team readiness assurance test in the team-based learning of physiology. Adv Physiol Educ. 2013;37:61-64.

22. Carbrey JM, Grochowski CO, Cawley J, Engle DL. A comparison of the effectiveness of the team-based learning readiness assessments completed at home to those completed in class. J Educ Eval Health Prof. 2015;12:5.

23. National Research Council. How People Learn: Brain, Mind, Experience, and School: Expanded Edition. Washington, DC: The National Academies Press; 2000.

24. Nader K, Schafe GE, Le Doux JE. Fear memories require protein synthesis in the amygdala for reconsolidation after retrieval. Nature. 2000;406:722.

25. McGaugh JL. Memory--A century of consolidation. Science. 2000;287:248-251.

26. Stickgold R. Sleep-dependent memory consolidation. Nature. 2005;437:1272-1278.

27. Glover JA. The “testing” phenomenon: Not gone but nearly forgotten. Journal of Educational Psychology. 1989;81:392-399.

28. Karpicke JD, Blunt JR. Retrieval practice produces more learning than elaborative studying with concept mapping. Science. 2011;331:772-775.

29. Roediger HL 3rd, Butler AC. The critical role of retrieval practice in long-term retention. Trends Cogn Sci. 2011;15:20-27.

30. Black P, Wiliam D. Assessment and classroom learning. Assessment in Education: Principles, Policy & Practice. 1998;5:7-74.

31. Smith MK, Wood WB, Adams WK, et al. Why peer discussion improves student performance on in-class concept questions. Science. 2009;323:122-124.

32. Springer L, Stanne ME, Donovan SS. Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. Review of Educational Research. 1999;69:21-51.

33. ten Cate O, Durning S. Peer teaching in medical education: Twelve reasons to move from theory to practice. Med Teach. 2007;29:591-599.

34. Tinto V. Classrooms as communities—Exploring the educational character of student persistence. Journal of Higher Education. 1997;68:599-623.

35. Schmidt HG, Van der Molen HT, Te Winkel WWR, Wijnen WHFW. Constructivist, problem-based learning does work: A meta-analysis of curricular comparisons involving a single medical school. Educational Psychologist. 2009;44:227-249.

36. Hattie J, Gan M. Instruction based on feedback. In: Alexander P, Mayer RE, eds. Handbook of Research on Learning and Instruction. New York, NY: Routledge; 2011.

37. Shute VJ. Focus on formative feedback. Review of Educational Research. 2008;78:153-189.

38. Van der Kleij FM, Feskens RCW, Eggen TJHM. Effects of feedback in a computer-based learning environment on students' learning outcomes: A meta-analysis. Review of Educational Research. 2015;85:475-511.

39. Perkins DN, Salomon G. Transfer of learning. In: International Encyclopedia of Education. Vol 2. Oxford, England: Pergamon Press; 1992.

40. Larsen-Freeman D. Transfer of learning transformed. Language Learning. 2013;63:107-129.

41. Gick ML, Holyoak KJ. Schema induction and analogical transfer. Cognitive Psychology. 1983;15:1-38.

42. Clements DH, Gullo DF. Effects of computer programming on young children's cognition. Journal of Educational Psychology. 1984;76:1051-1058.

43. Rajalingam P, Rotgans JI, Zary N, Ferenczi MA, Gagnon P, Low-Beer N. Implementation of team-based learning on a large scale: Three factors to keep in mind. Med Teach. 2018;40:582-588.

Table 1
Cognitive Activities Included in Team-Based Learning (TBL) and the Corresponding Psychological Processes that Strengthen Students' Conceptual Knowledge

TBL activity	Psychological process
Homework	Initial learning of material
Sleep	Consolidation
Classroom exercises	Reconsolidation
iRAT	Retrieval practice
tRAT	Peer elaboration
Burning questions	Feedback
Application exercises	Transfer

Abbreviations: iRAT indicates Individual Readiness Assurance Test; tRAT, Team Readiness Assurance Test.

Chart 1
The Three Consecutive Phases of Team-Based Learning[a]

Phase 1: Preparation (pre-class)	Phase 2: Readiness assurance (in-class)	Phase 3: Application (in-class)
Assigned study material	Individual test (iRAT)	Problem solving in teams
Individual preparation	Team test (tRAT) with immediate scoring	Simultaneous reporting of solutions
	Students seek clarification	Facilitated inter-team discussion
	Teachers offer feedback in response to "burning questions"	

Abbreviations: iRAT indicates Individual Readiness Assurance Test; tRAT, Team Readiness Assurance Test.
[a]Adapted from Michaelsen et al.[8]

Box 1

Case Used During a Team-Based Learning Application Exercise, Aimed at Encouraging the Transfer of Knowledge in Students, Adapted from a First-Year Cardiorespiratory Course at Lee Kong Chian School of Medicine, Singapore

A 30-year-old construction worker falls off a ladder while at work and suffers a fracture dislocation of his cervical spine at C6. On examination, he is tetraplegic and only able to move his shoulders bilaterally. His height is 1.75 m with a body weight of 70 kg.

Q1 Which of the following changes in lung volumes would you expect to find in this patient?

A. Increased functional residual capacity
B. Decreased inspiratory capacity
C. Increased vital capacity
D. Decreased residual volume
E. Unchanged tidal volume

Q2 You notice that he has more difficulty breathing when he is propped up in a sitting position but is able to breathe more comfortably when lowered flat onto the bed. What change occurs in the erect posture that causes this observation?

Q3 After three days, he grows progressively more tired with associated hypoventilation and increasing hypercapnia. He is transferred to the intensive care unit where he is intubated and started on mechanical ventilation. Which of the following settings on the ventilator will yield the highest minute alveolar ventilation?

A. Tidal volume of 600 ml and respiratory rate of 10/min
B. Tidal volume of 550 ml and respiratory rate of 12/min
C. Tidal volume of 500 ml and respiratory rate of 15/min
D. Tidal volume of 450 ml and respiratory rate of 18/min
E. Tidal volume of 400 ml and respiratory rate of 20/min