

## University of Groningen

### Knowledge and skills acquisition in medical students

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# **GENERAL INTRODUCTION**

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The aim of medical curricula is to encourage and support students to develop their knowledge and skills until they are competent to practice medicine. Many choices need to be made when designing a medical curriculum to ensure that students acquire knowledge and skills to the expected level of proficiency at graduation. These choices should reflect aspects of the curriculum that stimulate or facilitate students' learning processes. In this thesis, we investigated the relation between various aspects of the curriculum and students' knowledge and technical skills acquisition. In addition, we explored the use of a progress test to evaluate the relation between aspects of the curriculum and students' knowledge development.

## **CURRICULUM AND STUDENTS' KNOWLEDGE DEVELOPMENT**

There are two main approaches to investigate the effects of curriculum design and interventions on students' knowledge development: laboratory studies and curriculum-level studies. Laboratory studies are controlled experimental studies in which a control group receives the usual education, and curriculum-level studies are studies comparing different curricula or tracks at a curriculum level. Unfortunately, there seems to be a mismatch between the outcomes of both types of research. Laboratory studies, for example, have shown that a problem-based curriculum leads to better learning outcomes,<sup>1-3</sup> whereas curriculum-level studies revealed little or no difference in learning outcomes.<sup>4-7</sup> Although students who followed an active-learning curriculum were more engaged in their learning, graduated faster and more often than their peers in a more lecture-based curriculum,<sup>8-10</sup> they seemed to have similar knowledge levels.<sup>4-6</sup> The differences in results of laboratory and curriculum-level research show how difficult it is to translate laboratory research findings to practice.

In the medical education literature, there is disagreement about the cause of the mismatch between the results of both kinds of curriculum effect studies. In a recent editorial, Geoff Norman discussed the mismatch between laboratory studies and the real world of the medical curriculum.<sup>11</sup> On the one hand, the mismatch may be due to difficulties in conducting experimental studies in medical education,<sup>12</sup> but on the other hand, Albanese and Mitchell argue that curriculum-level research is often weak by its design.<sup>4</sup>

There are arguments for and against the use of laboratory and curriculum-level studies when investigating curriculum effects on medical students' learning outcomes. Norman and Schmidt criticized the use of laboratory studies to investigate curriculum interventions, arguing that (1) randomization, especially blinding the participants to their condition, is almost impossible in educational research; (2) controlling variables is very difficult because of the many variables involved in a curriculum; and (3) it is difficult to choose adequate student outcomes measurements because these may vary drastically across

medical curricula.<sup>13</sup> As a corollary, translating laboratory findings to a real curriculum is also difficult, because important factors that may determine the success or failure of the intervention in the real curriculum may have been omitted.<sup>12</sup> Controlling students' access to the study material, for example, may decrease the replicability of the study in a real curriculum where students' access to the study material is not controlled. Studies at curriculum level are often hampered by a lack of a proper control group. Often, historical control data, another track within the same school or a track from a different school have been used for the comparison.<sup>4,14-16</sup> Schmidt pointed out that research on students' learning outcomes over time may be influenced by many confounders, such as the use of volunteers as study participants, difficulties in establishing comparable groups, and differential exposure to the instrument that is used to measure curriculum effects.<sup>17</sup> These confounders may explain the difficulty of finding differences in students' knowledge levels when comparing different curricula. The confounders, however, could be understood as aspects of each individual curriculum. The answer may lie in identifying aspects of the curriculum in different curricula that may explain students' knowledge development.

In this thesis, aimed at identifying such aspects of the curriculum, students' knowledge development was compared between different curricula. Additionally, aspects of the curriculum that may have influenced students' knowledge development were investigated.

## **CURRICULUM AND TECHNICAL SKILLS ACQUISITION**

Medical curricula include technical and non-technical skills training. Technical skills are often considered motor or psychomotor skills that medical doctors need to perform. For example, suturing is a technical skill that all medical doctors have to learn. Non-technical skills are the cognitive and interpersonal skills that complement knowledge and technical skills.<sup>18</sup> The teaching of non-technical skills has been integrated in the medical curricula because of concerns that poor performance of non-technical skills could lead to errors or disciplinary actions.<sup>19, 20</sup> Nowadays, technical as well as non-technical skills are explicitly taught.

Technical and non-technical skills are part of both undergraduate and postgraduate medical curricula. Although different types of technical skills are relevant for each type of curriculum, non-technical skills training is very similar in both curricula. For example, some technical skills are only taught to residents because of the specificity of the specialty in question, whereas teamwork and communication skills are taught in under- and postgraduate training.

In the past decades, there has been an increase in research regarding non-technical skills in undergraduate medical training. The introduction of competency-based education was one of the reasons for this increase. Competency-based curricula not only focus on medical expertise (knowledge and technical skills), but also on attitude and behavior.

Competency frameworks (i.e. CanMEDS and Tomorrow's doctor) have been implemented widely in both undergraduate and postgraduate medical training.<sup>21,22</sup>

Technical skills have mostly been taught in the clinical setting, under the assumption that students gain competence over time simply by being exposed to patients and clinical experiences.<sup>23</sup> McGaghie et al. argued that this kind of training lacks structured learning objectives, skills practice and objective assessment with proper feedback.<sup>23</sup> Over the past decades, skills training in medical curricula has been shifting towards simulation training. In a simulated setting, students are offered the opportunity to practice their skills without time restrictions and with structured feedback. Aspects of the curriculum may affect students' skills acquisition either deliberately or unintentionally.

In addition to the relation between various aspects of the curriculum and students' knowledge development, this thesis investigates how various aspects of the curriculum affect students' technical skills acquisition.

## **CURRICULUM DESIGN**

Aspects of the curriculum reflect the embodiment of curriculum design, relating to the teaching methods, assessment programme or the rationale for the design. First, a short overview regarding curriculum design is given, after which the specific aspects of the curriculum investigated in this thesis are described.

According to Prideaux, at least four elements should be taken into account when designing a curriculum: content, teaching and learning strategies, assessment processes and evaluation processes.<sup>24</sup> In curriculum design, these elements are linked and should not be considered as separate steps. Since this thesis focusses on students' knowledge development and technical skills acquisition, the description of the four elements is from a students' perspective. The content of a curriculum focusses on the acquisition of knowledge, skills and attitudes (or competencies). Teaching and learning strategies refer to the didactics and pedagogy, for example whether the learning activities are student oriented, the teaching methods used and the opportunity to learn in real-life settings.<sup>24</sup> Assessment processes focus on evaluating students' knowledge, skills and attitudes, which requires a clear test blueprint and different stakes. Evaluation processes refer to students' feedback regarding the curriculum.<sup>24</sup> All these elements are chosen in a given context, which will influence the curriculum design (Figure 1). In this thesis, the focus is on aspects of the curriculum that either belong to the teaching and learning strategies or to the assessment processes.

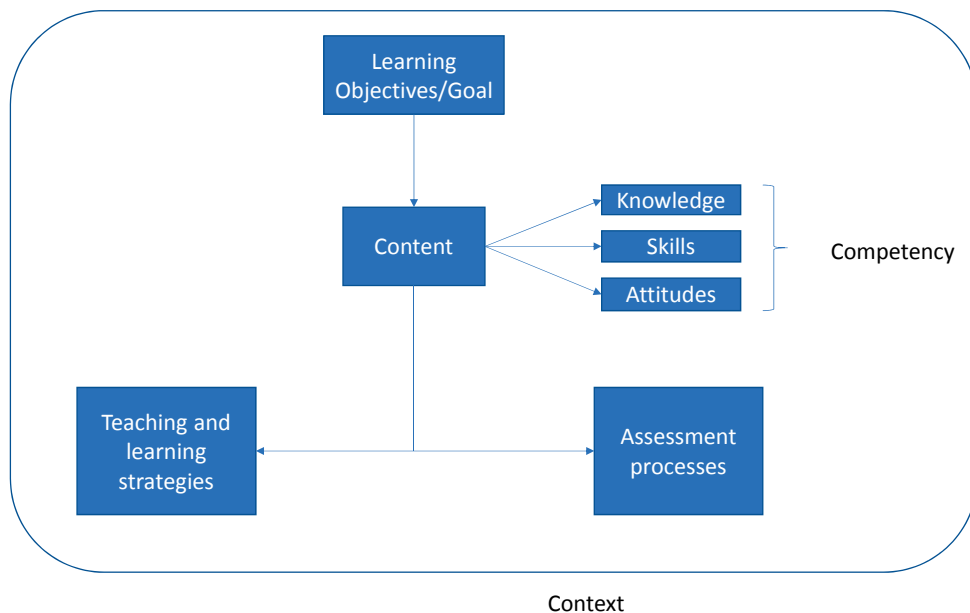


Figure 1. Figure adapted from Prideaux (2007)<sup>25</sup>

## TEACHING AND LEARNING STRATEGIES

### *Knowledge development*

Problem-based learning (PBL) has increasingly been used as a teaching and learning strategy in medical education. According to Schmidt, Cohen-Schotanus, and Arends,<sup>9</sup> PBL has six defining aspects: (1) problems as the starting point for learning, (2) small group collaboration, (3) flexible guidance of a tutor, (4) less lecture hours because (5) learning should be initiated by the students and (6) students need time for self-study. Although these six aspects are the core of problem-based learning, their intensity may vary between different problem-based curricula. In this thesis, we explored several aspects of the curriculum such as the degree of problem-based learning, the number of contact hours and whether a discipline is taught in a single, concentrated semester or spaced over a period of two or more semesters.

Only defining a curriculum as problem-based learning may be misleading, since many aspects of problem-based curricula may vary across different curricula. Severiens and Schmidt<sup>28</sup> found that students in an active-learning curriculum have higher levels of social and academic integration than students in a mixed curriculum (combination of lectures and some methods of active learning) and a lecture-based curriculum. Barrows classified a taxonomy of a problem-based curriculum based on four important objectives in medical education, (1) structuring knowledge in clinical cases, (2) developing a clinical reasoning process, (3) development of self-directed learning skills and (4) motivation for learning.<sup>29</sup>



This taxonomy intends to identify the degree to which these objectives are addressed in problem-based learning curricula.

With the implementation of PBL curricula, the number of contact hours was drastically decreased.<sup>9</sup> Research demonstrated that end-level students had acquired the same amount of knowledge, regardless of the number of contact hours they had.<sup>9,30</sup> Novice students who had more contact hours, however, had acquired more knowledge than students with less contact hours.<sup>30</sup> Usually, comparison of contact hours is made after curriculum change, for example, when a previous cohort is compared with the new cohort. In this thesis, however, we compare the number of contact hours across different medical schools, which allows us to investigate whether contact hours are important in different contexts.

Spacing a discipline over more than one semester is not a core aspect of PBL. However, studies from cognitive psychology have shown that spacing the study material over time instead of letting students study all material at a single moment (massed session) has been proven to improve long-term knowledge retention.<sup>26,27</sup> This so-called spacing effect is well-established for knowledge, but less for knowledge development in a naturalistic setting. To unravel knowledge transfer in a naturalistic setting, there is a need for studies exploring the effects of spaced learning sessions on knowledge development.

### ***Skill acquisition***

Medical students usually have to repeat a medical skill many times before they are able to perform it proficiently.<sup>23</sup> Technical skills training varies across curricula with large variations in training duration depending on the complexity of the skill and the availability of instructors, such as clinicians or other health care professionals. It is often not possible for curriculum developers to guarantee enough practice time for their trainees due to time and resource constraints. Finding an optimal training schedule, however, may reduce the amount of resources required as well as the number of trainings needed.

Feedback provides information to the students on how well they perform the actions of a task.<sup>31</sup> Furthermore, feedback can draw students' attention to important aspects of the task.<sup>32,33</sup> Interestingly, several studies have shown that it is more effective to focus on external information than on the actual movement.<sup>34-36</sup> Although feedback is essential for learning skills, there are still many aspects of feedback that are not clear, especially when the complexity of many medical skills is taken into account.

Traditionally, experts guide medical students' acquisition of a skill by telling and showing them what they have to do. With the use of a simulator, however, experts may take advantage of other formats of feedback. Many simulators have feedback features, such as help screens or haptic feedback. Combining different sources of feedback may reduce students' cognitive load during skill acquisition;<sup>33,37,38</sup> however, studies on the effects of combining different sources of feedback on medical skills retention are lacking.<sup>37</sup>

## ASSESSMENT

Assessment is key to ensure that students possess the necessary knowledge and can be designed in a way that it influences students' study strategies.<sup>39</sup> One way of steering students' study behaviour is by varying the type of questions in a test, which will influence what and how students study. Traditionally, types of questions are categorized as multiple-choice questions, open-ended questions, short answer questions, et cetera. Questions can also be categorized on the basis of the levels of Bloom's taxonomy, which would provide information about students' cognitive processing.<sup>40-42</sup> Another way of steering students' study behavior is by letting them decide and show whether they know the answer to a question.<sup>43</sup> This allows students to make a judgment about their knowledge and understanding, promoting students' ability to reflect on their own knowledge.

### *Bloom's taxonomy*

Students' cognitive processing is a cumulative hierarchy of lower and higher levels of acquired knowledge. Mastering the lower levels of the hierarchy is required before the higher levels can be achieved.<sup>42,44,45</sup> The two lower levels refer to remembering and a minimal understanding of facts and basic concepts.<sup>46</sup> The third level refers to applying the knowledge in a new situation. Whereas some researchers consider the third level as a transitional level,<sup>46</sup> others consider it as a higher level of cognitive processing.<sup>47</sup> The top three levels refer to drawing connections between ideas (analyzing), justifying a decision (evaluating) and creating new knowledge. They are considered as higher levels of cognitive processing,<sup>48</sup> at which a deeper understanding of the knowledge is required. However, the higher levels of cognitive processing are not necessarily hierarchically structured,<sup>46</sup> which implies that students may be able to evaluate knowledge without necessarily having to analyze their own knowledge. Since medical students are expected to use higher levels of cognitive processing when facing a patient, it is important to investigate how students develop their ability to apply knowledge.

### *Judgement of knowledge*

Since medical doctors have to make high-stake decisions regarding their patients, it is crucial that medical students recognize what they know and what they do not know.<sup>43</sup> Assessment may support students to develop their awareness of knowledge<sup>43</sup> by asking them to provide a judgment on their knowledge, which is known as metacognitive knowledge.<sup>45</sup> In designing a test, one can choose to make students aware of their knowledge gaps by offering an "I don't know" option to multiple-choice questions. Several studies have investigated students' judgments of knowledge in regular knowledge tests by adding such an "I don't know" option.<sup>43,49-51</sup> Besides increasing the reliability coefficients of the knowledge tests,<sup>43,49</sup> students' judgment of knowledge has a positive correlation with test scores. This indicates that the higher students score on their judgment of knowledge, the better their performance is.<sup>52,53</sup> It is not clear, however, whether the "I

don't know" option stimulates medical students to develop their judgment of knowledge, or what the effect of such aspects of the assessment are on students' test scores.

## RESEARCH CONTEXT

In the Netherlands, the medical curricula are designed in accordance with the Bologna principles, consisting of a three-year pre-clinical bachelor and a three-year clinical master. Five out of the six studies in this thesis were performed at the University Medical Center Groningen, the Netherlands.

The medical curriculum of the University of Groningen is a competency-based curriculum, in which basic and clinical sciences are taught in an integrated way using small groups active learning sessions that start with a problem. During the clinical phase (year 4-6), students complete 15 to 17 clinical rotations in total. In their first master's year, five-week periods of skills training (technical and non-technical) at the training centre are alternated with clerkship rotations at the hospital. In their second master's year, students complete clerkship rotations of 4 weeks each. In their third master's year, students have to choose a specialty for a clerkship that they will attend for 20 weeks. Students' knowledge, skills and competencies are assessed throughout the pre-clinical and clinical phase. All students sit the progress tests, but their knowledge is also assessed by block assessments, mainly in the preclinical phase.

Knowledge development is explored in the first four studies of this thesis, using naturalistic data from the Dutch interuniversity progress test. The progress test is based on the Dutch National Blueprint for the Medical curriculum and is administered four times a year. Each progress test consists of 200 multiple-choice questions covering the whole domain of medical knowledge at end level. The questions differ for each test. All questions have an "I don't know" alternative, hereafter called question mark option, allowing students not to answer a question. To calculate students' test scores, a formula scoring method is used as follows: a correct answer is awarded with one point; an incorrect answer with a negative mark, which varies according to the number of answering alternatives per question; and choosing the question mark option results in a score of zero points. For more information about the Dutch progress test, see Wrigley et al.,<sup>54</sup> Schuwirth & van der Vleuten,<sup>55</sup> and Tio et al.<sup>56</sup>

Progress test results data from 2007 to 2013 were retrieved from the universities of Leiden, Groningen, Nijmegen, and Maastricht. These data were used to explore the relation between medical students' growth of oncology knowledge and aspects of the curriculum. To reduce the number of confounding factors, growth of oncology knowledge was further explored in the bachelor phase (year 1-3) of the University of Groningen. At that time, there were two parallel bachelor programmes with the same learning objectives: a Dutch and an international bachelor. The international students took the progress test in English.

In the last two studies of this thesis, the focus shifts from knowledge acquisition to medical skills acquisition of undergraduate students. The last study of this thesis was conducted at the Wenckebach Skills Center of the University Medical Center Groningen.

## CENTRAL RESEARCH QUESTION

Medical curricula aim, among other things, to support students' learning. Evaluation of the curriculum often relies on students' feedback regarding their satisfaction with the curriculum or the logistics. Adding students' performance on knowledge tests to the curriculum evaluation process may give information about the relation between aspects of the curriculum and students' knowledge. Kirkpatrick developed and revised his framework to evaluate the effectiveness of a training.<sup>57</sup> This framework consists of four levels. The first level, *Reaction*, measures how participants react to the training by measuring their engagement and satisfaction with the training. The second level, *Learning*, assesses whether the participants acquired knowledge, skills, attitudes and competencies. The third level, *Behavior*, analyzes how trainees apply the information they received during the training and whether the training had an effect on the participants' work behavior. Finally, the fourth level, *Results*, assesses the outcomes of the training from an organizational perspective, i.e. whether the training had a positive effect on the organization. Looking at the Kirkpatrick's levels of evaluation, performance on a single knowledge test would allow us to measure the learning outcomes (Level 2), and performance on multiple knowledge tests over time would allow us to identify changes in students' behavior (Level 3).<sup>57</sup>

Since assessment is an aspect of the curriculum which influences students' study behaviour,<sup>61</sup> it is imperative to investigate assessment itself. Progress tests are valid and reliable assessment tools for measuring students' knowledge development over time,<sup>54</sup> while exerting a positive influence on student learning.<sup>55</sup> Furthermore, progress tests can be curriculum independent, for example, when the progress test is administered by a consortium.<sup>56</sup> Progress tests have also been used as a benchmark between medical schools, which allows the schools to assure that their students gain the same level of knowledge across different curricula.<sup>54,58-60</sup> Therefore, using the progress test to assess how aspects of the curriculum affect students' knowledge development seems logical.

Next to knowledge development, it is also important to understand how the aspects of the curriculum affect students' technical skills acquisition. Two specific aspects of the curriculum were investigated with respect to skills training: (1) feedback and (2) spacing of the training sessions.

Overall, this thesis sought to answer the following research question:

How do aspects of the curriculum relate to students' knowledge development and skill acquisition?

## CHAPTER OVERVIEW

This thesis investigates how aspects of the curriculum affect students' knowledge and skill acquisition. All studies in this thesis have been published or accepted for publication, except for Chapter 7, which has been submitted. Since the chapters of this thesis are based on articles written to be read on their own, repetition and overlap across the thesis is inevitable.

In **Chapter 2**, the relation was investigated between students' knowledge development of oncology and various aspects of the curriculum, such as the degree of problem-based learning within a curriculum, number of contact hours, adding of a pre-internship training (refreshment course before entering the clinical rotation) and spacing a discipline. This explorative study, using naturalistic data of four different curricula, could of course not control for many confounding factors. For example, the number of patient encounters for each student during the clinical phase, learning objectives, context and teachers could not be controlled. Therefore, in the next study, we analyzed two parallel cohorts within the same curriculum. Different from Chapter 2, in **Chapter 3**, the context, the teachers, teaching methods and the assignments were similar in both cohorts. In Chapter 3 a comparison in curriculum design was made between teaching a discipline in one semester or spacing it over the entire preclinical training phase within the Groningen curriculum. The main difference between these two tracks was the timing of the exposure to oncology: one track had a block semester and the other track had discipline-specific training spaced over the preclinical phase. The aim of this study was to compare knowledge growth of students taught in a concentrated semester with that of students taught in a spaced format.

Whereas in the first two chapters the focus was on knowledge acquisition, the next step was to explore knowledge application. At the end of their undergraduate training, medical students are not only expected to remember basic factual knowledge (lower order), but also to apply it (higher order). They also should be aware of their current knowledge as well as their lack of knowledge. The question mark option is an important aspect of the assessment that curriculum designers can use to support students to develop their judgment of knowledge. In **Chapter 4**, students' scores on lower and higher order progress test questions and their judgment of knowledge were compared. The question mark option in successive progress tests was used to measure students' judgment of knowledge. Besides the educational aspect of judgement of knowledge investigated in Chapter 4, it is important to verify the effect of the "question mark option" on students' scores. In **Chapter 5**, we investigated the effect of formula scoring by comparing students' scores on questions with (formula scoring) with scores on questions without the question mark option (number-right scoring). Different from previous studies, we used Rasch analysis to compare formula scoring with number-right scoring. In contrast to the classical test theory, Rasch analysis is more sensitive to construct-irrelevant sources of variance.

In the first four chapters, the focus is on knowledge acquisition and application, but in **Chapters 6 and 7** the focus shifts towards skill acquisition and retention. Whereas in Chapters 2 and 3 the effect of spacing a discipline was investigated with respect to knowledge development, in **Chapter 6** a systematic review was conducted to explore what is known about the spacing effect on medical skill retention. Finally, **Chapter 7** describes a randomized experiment to investigate the effects of different feedback formats on skills acquisition and retention. More specifically, we investigated whether students would acquire and retain their skills better after expert feedback, simulator feedback or a combination of both types of feedback.

## REFERENCES

1. Capon N, Kuhn D. What's so good about problem-based learning? *Cogn Instr.* 2004;22(1):61-79.
2. De Grave WS, Schmidt HG, Boshuizen HP. Effects of problem-based discussion on studying a subsequent text: A randomized trial among first year medical students. *Instr Sci.* 2001;29(1):33-44.
3. Schmidt HG, De Volder ML, De Grave WS, Moust JH, Patel VL. Explanatory models in the processing of science text: The role of prior knowledge activation through small-group discussion. *J Educ Psychol.* 1989;81(4):610.
4. Albanese MA, Mitchell S. Problem-based learning: a review of literature on its outcomes and implementation issues. *Acad Med.* 1993;68(1):52-81.
5. Vernon DT, Blake RL. Does problem-based learning work? A meta-analysis of evaluative research. *Acad Med.* 1993;68(7):550-563.
6. Dochy F, Segers M, Van den Bossche P, Gijbels D. Effects of problem-based learning: A meta-analysis. *Learn Instr.* 2003;13(5):533-568.
7. Schmidt H, Dauphinee WD, Patel VL. Comparing the effects of problem-based and conventional curricula in an international sample. *Acad Med.* 1987;62:305-315.
8. Van den Berg M, Hofman W. Student success in university education: A multi-measurement study of the impact of student and faculty factors on study progress. *High Educ.* 2005;50(3):413-446.
9. Schmidt HG, Cohen-schotanus J, Arends LR. Impact of problem-based, active learning on graduation rates for 10 generations of Dutch medical students. *Med Educ.* 2009;43(3):211-218.
10. Schmidt HG, Cohen-Schotanus J, Van Der Molen, et al. Learning more by being taught less: a "time-for-self-study" theory explaining curricular effects on graduation rate and study duration. *High Educ.* 2010;60(3):287-300.
11. Norman G. The birth and death of curricula. *Adv Health Sci Educ.* 2017;22:797.
12. Prideaux D. Researching the outcomes of educational interventions: a matter of design. RTCs have important limitations in evaluating educational interventions. *BMJ.* 2002;324(7330):126-127.
13. Norman GR, Schmidt HG. Effectiveness of problem-based learning curricula: Theory, practice and paper darts. *Med Educ.* 2000;34(9):721-728.
14. Kaufman DM, Mann KV. Achievement of students in a conventional and problem-based learning (PBL) curriculum. *Adv Health Sci Educ.* 1999;4(3):245-260.
15. Mennin SP, Friedman M, Skipper B, Kalishman S, Snyder J. Performances on the NBME I, II, and III by medical students in the problem-based learning and conventional tracks at the University of New Mexico. *Acad Med.* 1993;68(8):616-624.
16. Kaufman DM, Mann KV. Comparing students' attitudes in problem-based and conventional curricula. *Acad Med.* 1996;71(10):1096-1099.
17. Schmidt H. Innovative and conventional curricula compared: What can be said about their effects? In: Nooman ZH, Schmidt HG, Ezzat ES (Eds.). *Innovation in medical education: An evaluation of its present status.* New York: Springer 1990. p.1-7.
18. Gordon M, Darbyshire D, Baker P. Non-technical skills training to enhance patient safety: a systematic review. *Med Educ.* 2012;46(11):1042-1054.

19. Odell M. Human factors and patient safety: changing roles in critical care. *Aust Crit Care*. 2011;24(4):215-217.
20. Papadakis MA, Teherani A, Banach MA, Knettlar TR, Rattner SL, Stern DT, et al. Disciplinary action by medical boards and prior behavior in medical school. *N Engl J Med*. 2005;353(25):2673-2682.
21. Frank JR, Danoff D. The CanMEDS initiative: implementing an outcomes-based framework of physician competencies. *Med Teach*. 2007;29(7):642-647.
22. Ellaway R, Evans P, Mckillop J, Cameron H, Morrison J, Mckenzie H, et al. Cross-referencing the Scottish Doctor and Tomorrow's Doctors learning outcome frameworks. *Med Teach*. 2007;29(7):630-635.
23. McGaghie WC. Mastery Learning: It Is Time for Medical Education to Join the 21st Century. *Acad Med*. 2015;90(11):1438-1441.
24. Prideaux D. ABC of learning and teaching in medicine. Curriculum design. *BMJ*. 2003;326(7383):268-270.
25. Prideaux D. Curriculum development in medical education: from acronyms to dynamism. *Teach Teach Educ*. 2007;23(3):294-302.
26. Carpenter SK, Cepeda NJ, Rohrer D, Kang SHK, Pashler H. Using Spacing to Enhance Diverse Forms of Learning: Review of Recent Research and Implications for Instruction. *Educ Psychol Rev*. 2012;24(3):369-378.
27. Carpenter SK. Spacing and interleaving of study and practice. In: Benassi VA, Overson CE, Hakala CM (Eds.). Washington, DC, US: Society for the Teaching of Psychology; 2014. p. 131-141.
28. Severiens SE, Schmidt HG. Academic and social integration and study progress in problem based learning. *High Educ*. 2009;58(1):59.
29. Barrows HS. A taxonomy of problem-based learning methods. *Med Educ*. 1986;20(6):481-486.
30. Kerdijk W, Snoek JW, van Hell EA, Cohen-Schotanus J. The effect of implementing undergraduate competency-based medical education on students' knowledge acquisition, clinical performance and perceived preparedness for practice: a comparative study. *BMC Med Educ*. 2013;13(1):76.
31. Salmoni AW, Schmidt RA, Walter CB. Knowledge of results and motor learning: a review and critical reappraisal. *Psychol Bull*. 1984;95(3):355.
32. Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors. *Med Educ*. 2010;44(1):75-84.
33. Wulf G. Attentional focus and motor learning: A review of 10 years of research. *E-journal Bewegung und Training*. 2007;1(2-3):1-11.
34. Wulf G, Su J. An external focus of attention enhances golf shot accuracy in beginners and experts. *Res Q Exerc Sport*. 2007;78(4):384-389.
35. Wulf G, McConnel N, Gärtner M, Schwarz A. Enhancing the learning of sport skills through external-focus feedback. *J Mot Behav*. 2002;34(2):171-182.
36. Shea CH, Wulf G. Enhancing motor learning through external-focus instructions and feedback. *Hum Mov Sci*. 1999;18(4):553-571.
37. Hatala R, Cook DA, Zendejas B, Hamstra SJ, Brydges R. Feedback for simulation-based procedural skills training: a meta-analysis and critical narrative synthesis. *Adv Health Sci Educ*. 2014;19(2):251-272.
38. Wulf G, Shea CH. Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychon Bull Rev*. 2002;9(2):185-211.
39. Wood T. Assessment not only drives learning, it may also help learning. *Med Educ*. 2009;43(1):5-6.
40. Redfield DL, Rousseau EW. A meta-analysis of experimental research on



- teacher questioning behavior. *Rev Educ Res.* 1981;51(2):237-245.
41. Jensen JL, McDaniel MA, Woodard SM, Kummer TA. Teaching to the test... or testing to teach: exams requiring higher order thinking skills encourage greater conceptual understanding. *Educ Psychol Rev.* 2014;26(2):307-329.
  42. Anderson LW, Krathwohl DR, Bloom BS. A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. New York: Longman. 2001.
  43. Muijtjens AMM, Van Mameren H, Hoogenboom RJI, Evers JLH, Van der Vleuten CPM. The effect of a "don't know" option on test scores: number-right and formula scoring compared. *Med Educ.* 1999;33:267-75.
  44. Bloom BS. Taxonomy of Educational Objectives: The Classification of Education Goals. Cognitive Domain. Handbook 1. New York: Longman, 1956.
  45. Krathwohl DR. A revision of Bloom's taxonomy: An overview. *Theor Prac.* 2002;41(4):212-218.
  46. Crowe A, Dirks C, Wenderoth MP. Biology in bloom: implementing Bloom's Taxonomy to enhance student learning in biology. *CBE Life Sci Educ.* 2008;7(4):368-381.
  47. Bissell AN, Lemons PP. A new method for assessing critical thinking in the classroom. *BioScience.* 2006;56(1):66-72.
  48. Zoller U. Are lecture and learning compatible? Maybe for LOCS: Unlikely for HOCS. *J Chem Educ.* 1993;70(3):195.
  49. Keislar ER. Test Instructions and Scoring Method in True-False Tests. *J Exp Educ.* 1953;21(3):243-249.
  50. Traub RE, Hambleton RK, Singh B. Effects of Promised Reward and Threatened Penalty on Performance of a Multiple-Choice Vocabulary Test. *Educ Psychol Meas.* 1969;29(4):847-861.
  51. Bree K, Roman B. Teaching Students to Say "I Don't Know": Potential Methods and Implications. *Acad Psychiatry.* 2017;41:561.
  52. Koriat A, Sheffer L, Ma'ayan H. Comparing objective and subjective learning curves: judgments of learning exhibit increased underconfidence with practice. *J Exp Psychol.* 2002;131(2):147.
  53. Schleifer LL, Dull RB. Metacognition and performance in the accounting classroom. *Issues in Account Educ.* 2009;24(3):339-367.
  54. Wrigley W, Van der Vleuten CPM, Freeman A, Muijtjens A. A systemic framework for the progress test: strengths, constraints and issues: AMEE guide no. 71. *Med Teach.* 2012;31:683-97.
  55. Schuwirth LWT, Van der Vleuten CPM. The use of progress testing. *Perspect Med Educ.* 2012;1(1):24-30.
  56. Tio RA, Schutte B, Meiboom AA, Greidanus J, Dubois EA, Bremers AJ. The progress test of medicine: the Dutch experience. *Perspect Med Educ.* 2016;5(1):51-55.
  57. Kirkpatrick D. Great ideas revisited: revisiting Kirkpatrick's four-level model. *Training and Development.* 1996;50(1):54-59.
  58. Muijtjens AMM, Schuwirth LW, Cohen-Schotanus J, Thoben AJ, Van der Vleuten, CPM. Benchmarking by cross-institutional comparison of student achievement in a progress test. *Med Educ.* 2008;42(1):82-88.
  59. Muijtjens AM, Schuwirth LW, Cohen-Schotanus J, Van der Vleuten CPM. Differences in knowledge development exposed by multi-curricular progress test data. *Adv Health Sci Educ.* 2008;13(5):593-605.
  60. Brunk I, Schaubert S, Georg W. Do they know too little? An inter-institutional study on the anatomical knowledge of upper-year medical students based on multiple choice questions of a progress test. *Ann Anat.* 2017;209:93-100.

## CHAPTER 1

61. Norman G, Neville A, Blake JM, Mueller B. Assessment steers learning down the right road: impact of progress testing on licensing examination performance. *Med Teach*. 2010;32(6):496-499.

