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REFLECTIONS

Long-term retention of basic science knowledge: a review study

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Abstract In this paper, a review of long-term retention of basic science knowledge is presented. First, it is argued that retention of this knowledge has been a long-standing problem in medical education. Next, three types of studies are described that are employed in the literature to investigate long-term retention of knowledge in general. Subsequently, first the results of retention studies in general education are presented, followed by those of studies of basic science knowledge in medical education. The results of the review, in the general educational domain as well as in medical education, suggest that approximately two-third to three-fourth of knowledge will be retained after one year, with a further decrease to slightly below fifty percent in the next year. Finally, some recommendations are made for instructional strategies in curricula to improve long term retention of the subject matter dealt with.

Keywords Basic science knowledge · Long term retention · Review study

"All sorts of ideas, if left to themselves, are gradually forgotten"
Herman Ebbinghaus, in *Memory: A contribution to experimental psychology* (*Über das Gedächtnis*, 1885. Translated by Henry A. Ruger & Clara E. Bussenius).

Introduction

The longevity of basic science knowledge learned in medical school has been a source of concern, probably for as long as this knowledge is included in the curriculum, i.e., since the mid-1800s. More specifically, there is a widespread belief among physicians and medical

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educators that a substantial portion of the basic science information learned in the traditional preclinical years in medical school is lost during the final, predominantly clinical, years (e.g., Kennedy et al. 1981; Norman 2000). This belief is long-standing and highly immune to eradication. To give a few examples: Bethe (1928) believed that anatomical details, in particular, are quickly forgotten, because though they are necessary to pass the exam, they are not useful for the 'Praxis des Lebens' (practice of life). A few years later, Cole (1932, p. 253) introduced the term "disuse atrophy" to describe the fate of basic science knowledge once the medical student entered the wards. In their influential book on medical education, Miller et al. (1961, p. 69) considered it not uncommon for students to "retain a mere ten percent of the anatomy or biochemistry offered in the traditional first-year course," though they admit having no data to substantiate this estimate. By the end of the 1960s, Dornhorst and Hunter (1967, pp. 666–667) joined the choir by noticing that few students begin clinical work with "any broad understanding of human structure and function," and that many of them seem to have forgotten their preclinical work "amazingly quickly." Blizard et al. (1975, p. 252) characterized students' attitudes towards the basic sciences as: "...passing the examinations, forgetting the whole business, and then getting on with the job of becoming a doctor." Quite in line with this, Neame (1984, p. 702) asserted that "certainly many competent medical practitioners are able to remember almost none of their basic sciences." Again a decade later, Michael Bond pointed out that "the great bulk of what is taught is neither useful nor remembered" (in: Anderson 1993, p. 405). And this is just a small sample; many more examples could be added. To mitigate the position of the basic sciences in the medical curriculum, however, it should be noted that outside this domain, popular belief holds as well that students forget what they learned in school, usually within a short time after an exam (e.g., Higbee 1977; Tyler 1930).

So far, so good. However, despite strong claims about "remembering almost nothing," the few actual investigations of physicians' long term retention of basic science knowledge reveal a much less dismal picture. On second thoughts, this may not be really surprising, because if the popular belief were true, then formal education, including basic science education in medicine, would be "a colossal waste of time" (Ellis et al. 1998). To put it differently, the value of education depends largely upon the life span of what has been learned (Bahrick 2000), or, more specifically, in the event, it is what the medical student, and eventually the doctor, "can recollect over months and years that shapes the practice of medicine" (Sisson et al. 1992, p. 454), a view recently confirmed by Kerfoot et al. (2007). Besides, there is evidence that for very long retention intervals (e.g., a decade or more), a dissociation occurs between actual memory performance and individuals' confidence ratings of their own knowledge, which suggests that people are to a certain extent unaware that they still possess knowledge that they acquired long ago (e.g., Conway et al. 1991). Finally, it can not even be excluded that folk beliefs about "remembering almost nothing" may in itself exert a pernicious influence on learning: if students and teachers enter the classroom well indoctrinated with the philosophy that the factual material learners acquire will soon be lost, then why worry about learning it at all except for passing the exams (Kastrinos 1965)?

In this paper, we will present a review of what is known from empirical studies about the long term retention of knowledge in general, and basic science knowledge in particular. Given that our primary interest is basic science knowledge in medical school, we will confine the general part of the review largely to *semantic* knowledge acquired in a *formal* context (usually a school context, including self-directed study, bench work, and field trips). For practical purposes, we will define semantic or conceptual knowledge here as knowledge that can be expressed in verbal or symbolic descriptions and can be shared between individuals. Thus, we will largely leave out studies focussing primarily upon episodic or event knowledge or on skills (motor as well as verbal skills). We will also not extensively discuss laboratory studies of retention, though we will mention a few laboratory studies featuring exceptionally long retention intervals.

In addition, we will conceive of retention—and its complement, forgetting—in terms of knowledge decay (sometimes called knowledge attrition). Thus, we will not discuss: (a) loss of knowledge as a consequence of interference with or replacement by new, more updated knowledge; (b) loss of knowledge due to a physical or pathological cause (amnesia); and (c) forgetting as a function of age, rather than passing of time. Decay of knowledge always implies a period of nonuse—the retention interval (RI)—and it is obviously most salient and problematic in situations where individuals learn something that they may not be required to retrieve or use for an extended period of time (Arthur et al. 1998, p. 58).

We will start with some remarks about how knowledge retention is measured. Next, we will concisely sketch the three types of studies that have been used to investigate long term retention: laboratory, educational (classroom), and naturalistic studies. The advantages and shortcomings of these studies will be discussed, as well as their general upshot. Next, we will review what is known of long-term retention of basic science knowledge in medical education.[1] We will end the review by expanding on what students, teachers, course- or curriculum developers can do to optimize long-term retention of the knowledge they want learners to acquire and retain.

Assessing knowledge retention

It is important to point out that there is not a single agreed-upon measure of knowledge retention, but a number of different means, which may not always yield equivalent results. In educational contexts, the two measures most commonly used are *cued recall* (i.e., open-ended questions) and *recognition* (true-false questions). Multiple choice questions (MCQs) often draw upon a mixture of recall and recognition (Arzi et al. 1986).

Laboratory experiments

The typical feature of these experiments is the tight control exerted by the investigator over the most important aspects of the study: over selection of the participants, the learning conditions, the materials, the instruments used to measure retention, and, most importantly,

[1] It should be noted that we do not think there is any fundamental difference between basic science knowledge and clinical knowledge in terms of retentivity. Level of retention of clinical knowledge will be influenced by thoroughness of initial learning (exposure), length of the retention interval, and reinforcement during the retention interval. Probably, this latter factor will account for most of the differences in retention between basic science and clinical knowledge; in fact, for much clinical knowledge, the assumption of a nonuse retention interval (no reinforcement or rehearsal) may be difficult to maintain. For example, Hojat and Veloski (1984) found an inverse relationship between students' scores on NBME Part II psychiatry, gynecology/obstetrics, and surgery subtests and the time lapsed since they attended the corresponding clerkships, but no relationship between their knowledge of general internal medicine at the examination and the time that had passed since they attended the internal medicine clerkship. Hojat and Veloski (1984) attribute this to knowledge of general medicine being pervasively used during most clerkships, hence being reinforced or rehearsed regularly. Conversely, clinical knowledge and basic science knowledge that remain unused will suffer from similar attrition or decay.

over what happens to the learner during the retention interval. Conversely, a drawback of these studies is the generally very limited length of the retention interval.

Laboratory experiments of knowledge retention started in the 1880s with the influential work of Hermann Ebbinghaus (1966). Using himself as the single participant in his studies, Ebbinghaus investigated the retention of nonsense syllables after retention intervals of different lengths, with the aim of discovering 'pure' measures of retention. Quite consistently, he found what later came to be called the 'Ebbinghaus' curve of forgetting,' that is, a negatively accelerated forgetting function (e.g., Stroud 1940). This function is characterized by large losses at short retention intervals, after which the curve levels off to smaller (but incremental) losses at longer intervals. Most importantly, Ebbinghaus' curves have been found for meaningful materials as well; in general, the *form* of the retention curve is the same for both meaningless and meaningful materials, but the *level* of retention is considerably higher in the latter case (Briggs and Reed 1943; Hovland 1951, p. 645) and the time scale is much more expanded. Figure 1 presents an illustration of an Ebbinghaus' curve, based on Ebbinghaus' original data.

In a typical laboratory experiment, the retention interval is in the order of hours, or at most days. Yet, a few laboratory investigators have managed to conduct experiments involving considerably longer retention intervals (Allen and Reber 1980; Wickelgren 1972). In both studies, retention levels of 50–60% after an RI of two years were found, for meaningful materials. Recently, Mitchell (2006) found vestiges of memory of line drawings after an RI of *seventeen years* with many participants not even remembering the initial laboratory learning session at all. If anything, these results attest to the potential longevity of knowledge learned long ago.

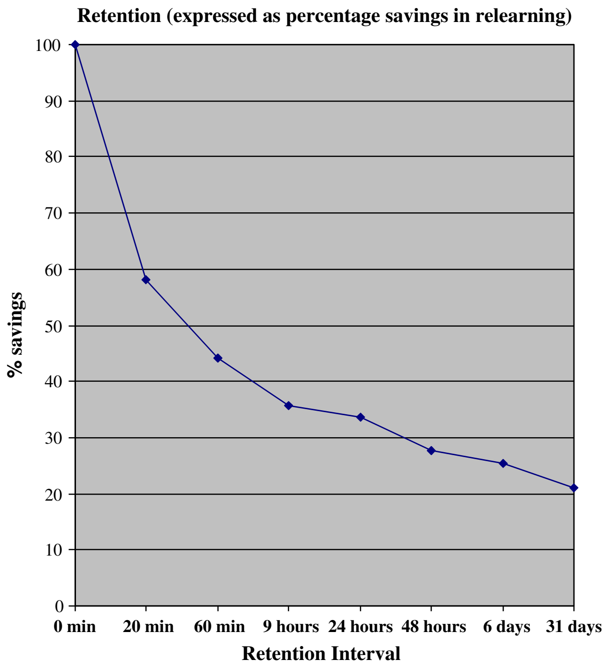

Fig. 1 Example of an Ebbinghaus curve. Retention expressed as percentage savings while relearning the materials after the RI (Ebbinghaus learned until he achieved 100% correct trials). Based on Ebbinghaus (1966, p. 103)

Educational (classroom) studies

Retention of knowledge learned in designated school courses has been a long-standing concern of educators and teachers; quite a few studies with this aim have been performed in the 1920s and 1930s, after which interest gradually waned, though occasionally new studies are published. Usually, advantage is taken of the fact that the participants remain enrolled in school during the retention interval, which makes them easily available for follow-up testing. Classroom learning differs from learning in the laboratory in that it takes place over several months (rather than in a single session or a few sessions), information is typically presented in a variety of ways, and the instructional content is more meaningful, varied, detailed, and complex; in other words, the context provides for multiple and distributed opportunities for learning and a more coherent organized content (Semb and Ellis 1994; Semb et al. 1993).

An appropriately conducted study in an educational setting starts with pretesting a sample of students on the relevant body of knowledge, to establish a baseline. Obviously, no pretest is necessary if the knowledge level in advance can safely assumed to be zero, such as in the case of novices learning a foreign language. After being pretested, students attend the course. Preferably, the study also includes a "control" group of randomly selected students who do not attend the course, to control for possible learning of the subject matter outside the classroom (e.g., Rickard et al. 1988). Alternatively, two types of educational interventions (e.g., a traditional and an innovative course) are compared for long-term knowledge retention (e.g., Holcomb et al. 1982; Kerfoot et al. 2006; Sinclair 1965). At course completion, all participants are posttested. Subsequently, the *knowledge gain* is calculated, expressed as percentage increase in scores between pretest and posttest. Finally, after the RI, a retention test is administered to both the control group and the experimental group, to determine *knowledge loss* i.e., the proportion of the knowledge gain that is lost at the retention test (Frutchey 1937; Semb and Ellis 1994).

Unfortunately, many educational studies, in particular the older ones, are not always properly conducted or reported, which complicates the review. The most important shortcoming is the failure to ascertain a truly nonuse RI: though students who take advanced courses in a discipline are usually not allowed to participate, it is clear that their being in contact with a domain is difficult to effectively prevent and can seriously compromise actual retention scores (in fact, Arzi et al. 1985, showed that even courses in *related* domains can boost retention of knowledge learned in a previous course). Another shortcoming is lack of specific information about the instrument used to assess the knowledge: few studies which employ MCQ-tests correct the scores for guessing, and in some cases, it is not even mentioned whether or not the test consisted of MCQs. If the remaining relevant information was provided, we calculated retention scores as if there was a chance level of 25% correct answers, a precaution that might have unfavorably biased estimates of the actual retention level.

The results of the review of educational studies are presented in Table 1. In a very general sense, most studies either positively support the existence of an Ebbinghaus' curve for long-term retention of meaningful material learned in school (e.g., Brooks and Bassett 1928; Johnson 1930; Powers 1925) or at least can be aligned with it (e.g., Cederstrom 1930; Eikenberry 1923; Eurich 1934; Greene 1931; Tyler 1933; Wert 1937). That is, most studies report relatively large losses for short retention intervals (months), which accumulate, but level off, for longer retention intervals (years). Yet, the actual time scale of the curves is rather divergent. A few studies report large losses over the course of less than one year (e.g., Greene 1931; Johnson 1930). The results of most studies are in the range of

Table 1 Review of educational long-term retention studies

Author(s), year	Domain	Participants	Type of test questions	Correction for guessing	Retention interval (RI)	Nonuse during RI[a]	% Retention
Arzi et al. (1986)	Chemistry	Grade 8–10 high school students ($N = 1176$)	MCQs	Yes	12 months	Probably	53% Overall
Bassett (1929)	History	Grade 6–8 high school students ($N = 1364$)	Mixed	No	4–16 months	Unlikely	86% (4 months), 79% (8 months), 74% (12 months), 63% (16 months)
Brooks and Bassett (1928)	American History	Junior high school pupils ($N = 459$)	Mixed	No	4–16 months	Unlikely	7/8 (4 months), 5/6 (8 months), 3/4 (12 months), 2/3 (16 months)
Cederstrom (1930)	Zoology	Zoology students ($N = 31$), premedical and predental students ($N = 56$)	Unknown	No	12 months	Possibly	75% on Scale A, 63% on Scale B
Eikenberry (1923)	Different high school disciplines	Senior college students ($N = 34$)	Unknown	No	2–4 years	Depending on discipline	Physics: 26%, chemistry: 45%, Latin: 55%, geometry: 86%, history: 87% to 127%
Ellis et al. (1998)	Child psychology	Former university psychology students ($N = 1158$)	Mixed	Yes	3–16 years	Probably	Factual knowledge: 38%, concept application: 15%
Eurich (1934)	General psychology	Educational psychology students ($N = 283$)	Mixed	No	6–9 months	Unclear	90% after 6 months (MCQs), 73% after 9 months (completion items)
Frutchey (1937)	Chemistry	High school students ($N = 96$)	Mixed	No	1 year	Unclear	81% Overall retention

Table 1 continued

Author(s), year	Domain	Participants	Type of test questions	Correction for guessing	Retention interval (RI)	Nonuse during RI[a]	% Retention
Glasnapp et al. (1978)	Measurement course for teacher trainees	Teacher trainees ($N = 396$)	MCQs	No	4–16 months	Unclear	After 16 months: mastery group 80%, nonmastery group 67%
Greene (1931)	Zoology, psychology, physiological chemistry	College zoology freshmen ($N = 407$), college psychology sophomores ($N = 525$), first-year medical students ($N = 130$)	Mixed	No	3½–20 months	Probably	At 3½ months: 55% of zoology; 60% of psychology; 60% of physiological chemistry; at 20 months: 10%–20% all disciplines
Holcomb et al. (1982)	Cardiovascular health knowledge	Grade 9 high school students ($N = 112$)	Unknown	No	6 months	Probably	85% (experimental group), 92% (control group)
Johnson (1930)	Elementary general botany	University biology freshmen ($N = 128$)	Mixed	Yes	3, 15, and 27 months	Unclear	54% (3 months), 26% (15 months), 24% (27 months)
Kastrinos (1965)	College preparatory biology	High school students preparing for college ($N = 28$)	MCQs (Probably)	No	2 years	Probably	83% after two years
McDougall (1958)	Educational psychology	Teacher trainees ($N = 172$)	MCQs	No	4 months	Probably	73%–79%, depending on type of knowledge
McKeachie and Solomon (1957)	General psychology	Educational psychology students ($N = 116$)	MCQs	No	3 and 7 months	Possibly	81% after 3 months, 82% after 7 months
Naveh-Benjamin (1988)	Research methodology	University students ($N = 58$)	Concept sorting	No	1 and 2 years	Definitely not	Higher levels: 90% (1 year), 85% (2 years); lower levels: 63% (1 year and 2 years)

Table 1 continued

Author(s), year	Domain	Participants	Type of test questions	Correction for guessing	Retention interval (RI)	Nonuse during RI[a]	% Retention
Powers (1925)	High school chemistry	Freshmen entering the university ($N = 349$)	Mixed	No	3 to 51 + months	Unclear	92% (3 months), 63% (15 months), 49% (27 months), 43% (39 months), 30% (51 + months)
Rickard et al. (1988)	Introductory psychology	Lower division undergraduate university students ($N = 74$)	MCQs	No	4 months	Possibly	70% after 4 months
Semb et al. (1993)	Introductory child psychology	University students ($N = 37$)	Mixed	No	4 and 11 months	Unclear	85% (4 months) and 80% (11 months) MCQs; 75% (4 months) and 70% (11 months) mixed format questions
Tyler (1930)	General science	Grade 9 high school students ($N = 68$)	MCQs	No	8 months	Probably	60% (factual knowledge); 87%–90% (explanations and generalizations)
Tyler (1933)	Elementary zoology	University students ($N = 82$)	Open end mixed	No	15 months	Probably	74%–79% for factual knowledge

[a] As much as possible independently assessed, without taking retention performance into account

two-thirds to three-fourths retention of knowledge gained in school or college courses after an RI of about a year (Bassett 1929; Brooks and Bassett 1928; Cederstrom 1930; Eurich 1934; Frutchey 1937; Kastrinos 1965; McKeachie and Solomon 1957; Semb et al. 1993; Tyler 1933; Watt 1987; Wert 1937). As rather divergent disciplines (e.g., history, psychology, zoology) are included, and the design of these studies also varies substantially, it is not unlikely that 70% retention after an RI of one year can be considered the modal retention value. The few educational studies that include RIs beyond one year report further decreases of retention, in line with the Ebbinghaus' curve, up to 30% retention of high school chemistry after an RI of four years (Eikenberry 1923; Wert 1937; Powers 1925).

Naturalistic studies

This is the only feasible type of study for retention intervals exceeding a few years. A large number of participants are tested for memory of a domain to which they were exposed (many) years before and with which they have not been in contact for intervals of various lengths (Bahrick 1979, 1993, 2000). In the analysis, retention is related to the participants' knowledge level at the end of the exposure (often expressed as number and level of courses attended) and the length of the RI. Due to the non-longitudinal character of this type of study, retention curves can only be reconstructed, though reliable information about the amount or proportion of forgetting can be collected (Stroud 1940). For those long time spans, groups of participants who have learned the material under similar circumstances may be hard to find (Bahrick 1993; Schmidt et al. 2000); in fact, it may not entirely be clear whether they learned the same knowledge at all, in particular for knowledge domains that change over time (Day et al. 1988). For example, did individuals who attended a preclinical physiology course in the 1950s, end up with the same knowledge as individuals who attended such a course in the 1980s?

Harry Bahrick and colleagues, who have performed a substantial number of naturalistic studies on retention of knowledge learned in a formal educational context after an extended interval of nonuse, have quite consistently found a triphasic retention curve for this type of knowledge (e.g., Bahrick 1979, 1984, 1992; Bahrick and Hall 1991a, 1991b; Bahrick and Phelps 1987). During the first phase, which lasts up till about six years after the last learning session, the knowledge graph shows an inversed exponential decline (positively skewed curve), similar to the Ebbinghaus' curve. The second phase lasts from approximately 6 until approximately 25–30 years after learning; as the forgetting curve in this phase is flat, Bahrick and colleagues dubbed it "permastore," because knowledge is apparently permanently retrievable in this phase. In the third phase, finally, again some loss of knowledge is found, which is probably age-related. In this phase, the knowledge curve is negatively skewed (Bahrick 1984, pp. 22–23).

Though the notion of a permastore of knowledge immune to forgetting appears somewhat counterintuitive, other studies have confirmed its existence (e.g., Conway et al. 1991; Conway et al. 1992; Ellis et al. 1998; Schmidt et al. 2000; Semb et al. 1993). For example, Conway et al. (1991) found that after a retention interval of 10 years, during which virtually no rehearsal took place, students retained a significant portion of knowledge of cognitive psychology, learned in an Open University course. Similarly, Ellis et al. (1998) found retention proportions for factual knowledge of a course in Child Behavior and Development for RIs ranging from 7 to 14 years of approximately one-third of the original knowledge. Though little can be said about the reliability of this proportional estimate, the important message is that a considerable proportion of factual knowledge learned long ago will be both retained and retrievable over a protracted time span (Bahrick 1984; Semb et al. 1993). The most interesting question is, of course: how can knowledge achieve this, from an educational perspective, enviable status? According to Bahrick (1979, 1984) and Conway et al. (1991), the knowledge should be acquired over an extended period in a cycle of repeated relearnings or rehearsals. That is, the *number* of courses an individual has taken in a particular subject is a much more important determinant of knowledge maintenance than a high grade received in a *single* course (Bahrick 1984; Bahrick and Hall 1991a), though course grades predict retention test performances on the short term relatively well (Bahrick 1984; Bahrick and Hall 1991a; Blizard et al. 1975).

Based on this and related findings, Conway et al. (1992) conclude that "the belief in rapid and near-complete loss of formally acquired knowledge is false. In fact almost the reverse is true, and knowledge originally acquired through formal education is retained to a high level for many years after the completion of secondary and tertiary education. Furthermore, this is the case even though this knowledge has remained unused since school and university days" (p. 467). In line with this conclusion, we would predict the permastore phenomenon to hold in the medical domain as well.

Long-term retention of basic science knowledge learned in medical school

The first reference to an investigation of long-term retention of knowledge learned in medical school can be found in Miller (1962). Unfortunately, we only learn that none of the sophomores, juniors, and seniors who took a second time examinations they had passed as freshmen, passed again in gross anatomy or biochemistry, and very few would have gotten by in microscopic anatomy and in physiology. As we do not know by which margin they passed the initial tests, quantitative estimates of retention are precluded. The same holds for a study of retention of gross anatomy performed at the University of Illinois College of Medicine (published in a report to the faculty in 1963) in which forgetting curves were found "that had exactly the same shape as the one first reported by Ebbinghaus" (Shulman 1970, p. 95). Thus, the first to publish actual results of a retention study in medicine to a broad audience was Weitman (1964). In this study, second year medical students were tested after an RI of 15 weeks for retention of knowledge of an introductory course in physiology. On this retest, their scores averaged approximately 80% of the end of course test scores, an outcome, which Weitman (1964) characterized as "quite high" (p. 88).

In the four decades following these early studies, a number of additional studies testing long-term retention of basic science knowledge learned in medical school has been published. Unfortunately, many studies suffer from the same shortcomings as the educational studies discussed in the previous section; for example, few studies attempted to control for rehearsal or relearning during the retention interval, the early study by Weitman (1964) being an exception. In addition, in some studies retention is expressed in pass-fail terms or as decreases in standard deviations, whereas the absolute level of the scores would have been more informative (Blizard et al. 1975; Levine and Forman 1973). Table 2 presents the results of a number of basic science retention studies. Contrary to the 'educational lore,' they have consistently revealed a relatively modest decline in retention of basic science knowledge during the first clinical year (the first year after termination of basic science training). In fact, the modal two-third to three-fourth retention after one year found in the general educational studies might very well hold for basic science studies in medical education. At the extremes are, on the one hand the Sinclair (1965) study, quite

Table 2 Review of basic science knowledge long-term retention studies

Author(s), year	Domain	Participants	Type of test questions	Correction for guessing	Retention interval (RI)	Nonuse during RI[a]	% Retention
Blizard et al. (1975)	Physics, biochemistry	Second year medical students ($N = 225$), 3rd year medical students ($N = 236$)	Open end	n.a.	4 and 16 months	Unclear	Two-thirds of students tested at either RI failed both physics and chemistry test
Blunt and Blizard (1975)	Anatomy	Second year medical students (N = 178), third year medical students ($N = 126$)	MCQs	No	12 and 21 months	Unlikely	75% after both 12 and 21 months
D'Eon (2006)	Immunology, physiology, neuroanatomy	Second year medical students ($N = 29$)	Unknown		10–11 months	Depending on discipline	Physiology and immunology: 80%; neuroanatomy: 47.5%
Donovan et al. (1969)	General basic science knowledge	Fourth year medical students (Univ Rochester School of Medicine, classes 1964–1971) ($N =$ 70–75 per class)	MCQs ("Minitest")	No	12 and 24 months	Unlikely	Little or no decrement (12 mo), significant decrement (24 mo)
DuBois et al. (1969)	Anatomy, biochemistry, microbiology, pathology, pharmacology, physiology	Second year medical students (controls), postgraduates ($N = 89$; longitude: $N = 12$), control group postgraduates ($N = 7$)	MCQs (NBME Part 1)	No	4–6 years	Unlikely	73% after 4–6 years
Harrison (1995)	3rd year Behavioral Sciences	Fourth year medical students ($N = 16$)	Open end	n.a.	1 year	Unlikely	75% after 1 year

Table 2 continued

Author(s), year	Domain	Participants	Type of test questions	Correction for guessing	Retention interval (RI)	Nonuse during RI[a]	% Retention
Herzig et al. (2003)	Pharmacology	Third and fourth year medical students; graduates nine months after graduation (*N* = 90 cross-sectional; *N* = 32 longitude)	Mixed	No	9 months	Probably	80% Nine months after graduation
Kennedy et al. (1981)	Anatomy, physiology, behavioral sciences, biochemistry, microbiology, pathology, pharmacology	Medical students at Part II NBME (*N* = 2640 longitudinal, *N* = 5280 cross-sectional)	MCQs ("Minitest")	No	Almost 2 years	Depending on discipline	Biochemistry 66%, anatomy 83%, microbiology 88%, physiology 94%, bahavioral sciences 108%, pathology 109%, pharmacology 110% (at almost 2 years)
Krebs et al. (1997)	First-year biology	Fourth year medical students in 6-year curriculum (*N* = 37)	Mixed	Yes	2½ years	Probably	56% retention after 2½ years for items deemed non-relevant
Lazic et al. (2006)	Physiology, biochemistry	Second year (*N* = 145) and fifth year (*N* = 176) medical students	Unknown		3 years	Possibly	70% after 3 years
Levine and Forman (1973)	Neurosciences (interdisciplinary course)	Junior medical students	MCQs		1 year	Unclear	38% at or above minimum pass level after 1 year

Table 2 continued

Author(s), year	Domain	Participants	Type of test questions	Correction for guessing	Retention interval (RI)	Nonuse during RI[a]	% Retention
Rico et al (1981)	Biochemistry	Second year medical students ($N = 100$), 4th year medical students ($N = 60$), 6th year medical students ($N = 49$), postgraduate medical residents ($N = 20$)	MCQs	Yes	1, 3, 5, and 8 years	Depending on topic	70% (1 year), 52% (3 yearrs), 51% (5 years), 40% (8 years)
Rodriguez et al. (2002)	Pharmacology	Third year medical students ($N = 584$)	MCQs	No	8 months	Unlikely	>100% (8 months)
Saffran et al. (1981)	Biochemistry	Fourth year medical students ($N = 2600$)	MCQs	Yes[b]	22 months	Depending on topic	66% (22 months)
Saffran et al. (1982)	Pharmacology	Fourth year medical students (N not mentioned)	MCQs	No	22 months	Definitely not	>100% (22 months)
Schwartz (1981)	Clinical biochemistry	Senior medical students ($N = 166$)	Open end	n.a.	6 months	Unlikely	82% (6 months)
Sinclair (1965)	Anatomy	Medical students (cohorts 1959–1963)	Mixed	No	2 years	Possibly	not above chance level after 2 years
Swanson et al. (1996)	All basic sciences in curriculum	US and Canadian students at Part I and Part II of NBME ($N = 3{,}722$)	MCQs	Yes[b]	15 months	Depending on discipline	94% (15 months)
Watt (1987)	Oral biology	Dental students ($N = 217$)	True-false	No	20 months	Probably	78.5% (20 months)
Weitman (1964)	Introductory physiology	Medical freshmen ($N = 73$)	MCQs	Not necessary	15 weeks	Most students definitely not	80% (15 weeks)

[a] As much as possible independently assessed, without taking retention performance into account

[b] Correction performed by authors

exceptionally confirming the belief of "remembering almost nothing," and on the other hand a study by Swanson et al. (1996) in which 94% retention after 15 months was reported. From Table 2, it can be read that different basic sciences yield different retention results. At an even more detailed level, Swanson et al. (1996) found that knowledge organized around specific organ systems (e.g., gastrointestinal, cardiovascular) is better retained than general knowledge not assignable to a specific organ system, and that performance on basic science items which concerned abnormal processes (i.e., knowledge related to principles of treatment and mechanisms of disease) actually improved, whereas performance on normal-process items declined substantially. Given the fact that the RI covered (parts of) the clinical years, better retention of abnormal processes does not come as a surprise. Similarly, within biochemistry, Saffran et al. (1982) found that test items that deal with cellular biochemistry suffered a greater loss in retention than did the items that deal with tissue, organ and whole body biochemistry. The biggest drop in performance occurred for an item dealing with the role of lipoic acid in intermediary metabolism, a topic that is unrelated to any major clinical situation (Kennedy et al. 1981).

In general, differences in retention between basic sciences can probably be accounted for by differences in rehearsal or reinforcement during the RI: The three studies that reported over 100% retention all involved pharmacology, whereas biochemistry appears to be a more vulnerable subject, though the study encompassing the longest retention interval in our sample, i.c. Rico et al. (1981), still found approximately 40% retention of this discipline after an RI of eight years. For the other basic sciences, the general picture is that gross anatomy shows a modest loss (Blunt and Blizard 1975; DuBois et al. 1969; Kennedy et al. 1981), while reports for physiology and microbiology range from no decrement (DuBois et al. 1969) to moderate decrements (Kennedy et al. 1981). However, to avoid the impression that these results are solely determined by differences in students' rehearsal of the knowledge during the RI, it is worth noticing that there is no evidence that *incidental* contact with a domain—in the order of a few hours during an RI that is measured in months or years—has a detectable effect on retention (Bahrick 1984; Weitman 1964). Thus, to the extent that students, during their clinical years, are only incidentally confronted with disciplines such as biochemistry, retention test scores will show the same losses as after a 'true' nonuse-RI. In this respect, the approximately 56% retention of non-relevant first-year biology after an RI of two years in the study by Krebs et al. (1997), as well as the 40% retention of biochemistry after eight years reported by Rico et al. (1981), are in line with, or slightly higher than, the results of the educational studies discussed in the previous section: around 70% retention after one year of nonuse, 40%–50% after two years, and 30% after four years or more. Given the dearth of *real* long term retention studies (with RIs beyond two years) in medical education, and the fact that, according to Bahrick's theory, knowledge needs to be retrievable for at least five years after learning has terminated before it can assumed to be in permastore, the available findings as yet are inconclusive as to whether basic science knowledge acquired by medical students can achieve this enduring status.

Discussion

The review presented in this paper shows that few studies actually support the assumption that almost all knowledge learned in school, including basic science knowledge in medical school, will be lost in the course of a few years. Indeed, a sizeable proportion of basic science knowledge will be retained, even if it has remained fallow during a prolonged period. Largely, the evidence is consistent with the rule of thumb that after an RI of one year, approximately one-third of the knowledge gain is lost, accumulating to slightly over one-half after a few years. Beyond this time span, the speed of loss slows, and the few available studies suggest that even after 8 years or more, a sizeable proportion of knowledge remains retrievable. At least, this holds for factual knowledge acquired in regular educational courses by students in general. That is, the results may not unconditionally generalize to other types of knowledge or skills, nor to every single individual student. Yet, they have been found to apply to a wide spectrum of disciplines and courses of the academic type. In general, our review suggests that the figures in an old but popular monograph—50% retention after one year and 25% after two years if knowledge is not used in the meantime—are a bit on the pessimistic side (Tyler 1949, p. 73). However, compared with the conclusion in Semb and Ellis (1994) review—84% retention if measured by recognition and 72% if measured by recall across all RIs—our estimation tends to be a bit more conservative.

Of course, the figures can also be read as large losses over the course of a few years; in other words, depending on one's attitude, the glass can be viewed as either half full or half empty. As already noticed, if knowledge retention is judged in terms of passing or failing a test, even relatively small losses may result in a large proportion of students 'flunking' (e.g., Rickard et al. 1988; Rico et al. 1981), and results may appear more dramatic than they actually are. Consequently, this way of assessing knowledge may contribute to the belief of "remembering almost nothing." According to Saffran et al. (1981), it is up to the faculty to decide whether they are satisfied with the level of retention demonstrated by their students, but if they are not and they consider what they offer worthwhile to be remembered, it makes sense to reinforce it in successive courses. If it is not, de-emphasizing it in the curriculum should be an option. Though the belief that medical students need to understand the basic facts and principles about the structure and functions of the human body is often endorsed (e.g., Neville 2000), the 'traditional' argument that medical students acquire knowledge in the basic science years in order to apply it in the clinical years (e.g., Levine and Forman 1973) is, latterly, less often heard. It should be emphasized that there will be no retention problem if knowledge is frequently used after formal instruction has terminated. However, if it is to be retained over prolonged periods of nonuse, it may be profitable to take note of studies that address those factors during learning that enhance long term retention, factors described by Bahrick as providing "immunity against forgetting" (Neisser 1984).

What are those factors? It is clear that the content and tasks to be learned, the conditions of retrieval, and individual students' abilities play a role in long-term retention (Farr 1987), but these are not under control of educators or instructors. The most important determinant of long-term retention, the available evidence suggests, is prolonged contact with a domain (Bahrick 1984; Conway et al. 1992). Though this may sound obvious, it also implies that training students to achieve high levels in short courses is less effective. That is, though it will take lower ability students more time (or more courses) to reach the same level of knowledge as higher ability students, in the end they may retain more of this knowledge. This is not to deny that better students generally learn and retain more if they attend the same courses as more mediocre students, but it has been observed that there are no differences in rate of forgetting or relative loss scores, which implies that the top students, in absolute terms, forget more material (Harrison 1995; Semb and Ellis 1994). In fact, instructional strategies that aim at mastery learning, such as the Personalized System of Instruction, may capitalize on this effect of extended exposure.

In terms of instructional approaches, the literature provides suggestions as to how to design a course, or even an entire curriculum, in order to optimize long-term retention of knowledge. The key issues are: (1) make systematic use of distributed or spaced practice, preferably in the form of (2) an expanding ratio, i.e., with increasing intervals between learning sessions, with (3) as much variable practice as possible, and (4) with use of frequent testing (Bahrick 2000; Bahrick and Hall 1991b; Landauer and Ainslie 1975; Landauer and Bjork 1978; Naveh-Benjamin 1990; Rea and Modigliani 1988; Schmidt and Bjork 1992). The aim is to achieve a certain level of mastery (overlearning), to make knowledge accessible regardless of the context in which it is to be retrieved (Roediger and Karpicke 2006, p. 190), to eventually achieve immunity to forgetting (Bahrick 2000). In concrete terms, this boils down to the following recommendations:

(a) Make sure that the course contains brief, appropriately spaced learning or practice sessions (Bahrick 2000). Already eighty years ago, Brooks and Bassett (1928) recommended that reviews be continued at least during the early part of the semester following the one in which the material is presented.
(b) Avoid cramming or prolonged intensive pre-examination revision (Bahrick 1992). It should be noted that it is in particular the prolonged (massed) aspect of cramming that is detrimental; repeated short bouts of cramming (intensive study), as well as short episodes of drill (repetitive practice) might have a beneficial effect (Bahrick 1979; Farr 1987). According to Miller et al. (1961) "the repetitive act must be the student's, not the teacher's" (p. 60).
(c) Courses should be appropriately graded, with advance courses starting with a review of the knowledge dealt with in earlier courses. If possible, advanced courses should be designed as to retroactively reinforce the consolidation of knowledge accumulated in previous courses (Arzi et al. 1985, p. 385).
(d) Students should be frequently tested by interim tests and end-of-course tests. Memory tests are powerful vehicles for improving long-term retention (e.g., Bangert-Drowns et al. 1991; Landauer and Ainslie 1975; Roediger and Karpicke 2006). The use of progress tests, to be administered at regular intervals, should be encouraged. Tests should always be comprehensive; that is, interim tests should not be used for exemption purposes. Final course examinations should be cumulative (Bahrick 2000). As tests work best for knowledge that learners still can retrieve, the level of difficulty of interim tests should be appropriate: all students who have seriously prepared for the test should be able to attain a high mark. If formative tests are used, care should be taken that students take them serious, and approach them as if they were summative tests. In this respect, the role of lectures in modern curricula might be reconsidered as well: presenting important material in a lecture which supplements small group learning and self study might be a relatively natural way to add another learning session in a distributed practice program.

Once formal instruction has ended, an obvious recommendation is to rehearse or restudy the to be retained knowledge at regular intervals during the retention interval. DuBois et al. (1969) recommend that physicians take refresher courses in the basic sciences to the equivalent of one lecture hour every week, or—more ambitious—five to ten days away from practice once or twice a year, living at a teaching center where they can attend lectures in sciences, take part in rounds and clinics, and thereby renew their position in the fields of basic and clinical science. Practical considerations, however, might limit the feasibility of such refresher training. More promising might be the explicit aim of many medical curricula nowadays to train students to become self-directed, lifelong learners, but we know of no study which has investigated medical practitioners' actual self-instigated study of the basic sciences after graduation. Therefore, the emphasis should rather be on prevention of forgetting—by implementing conditions during courses that lead to a high level of original learning and enhanced retention, as outlined above—rather than on repair once forgetting has occurred (Christina and Bjork 1991).

Finally, some readers may have noticed that currently popular notions of meaningful learning and providing appropriate contexts for learning are not included among these recommendations. This does not imply, however, that these aspects are considered irrelevant. Partly they are embraced, by the abovementioned points; for example, starting an advanced course with a recapitulation of a previous course can be conceived of as both providing a context for subsequent learning and a rehearsal session. Similarly, lecturers can make knowledge more meaningful by providing a different, e.g., more encompassing, view of the subject. As Neisser (1984) suggests, coherence, and hence better retention, can be increased by presenting as much knowledge in context, e.g., basic science knowledge in a clinical context. However, if the aim of providing knowledge in such a context is to enhance retrievability in precisely that context, there is evidence that this does not work (Koens et al. 2003). Rather than presenting knowledge in the predicted context of future application, it would be more advantageous to present materials in different contexts, which increases encoding variability and also implies a form of spaced learning. Indeed, one might question whether knowledge, if it can only be retrieved in specific contexts, can really be called "permanent." Implicitly, retention of knowledge in all studies included in this review is defined as "being retrievable (recall or recognition) at a surprise retention test," and the actual practice of medicine might be conceived as a context in which such surprise retention tests at regular intervals are administered.

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