At the heart of learning: navigating towards educational neuroscience in health professions education

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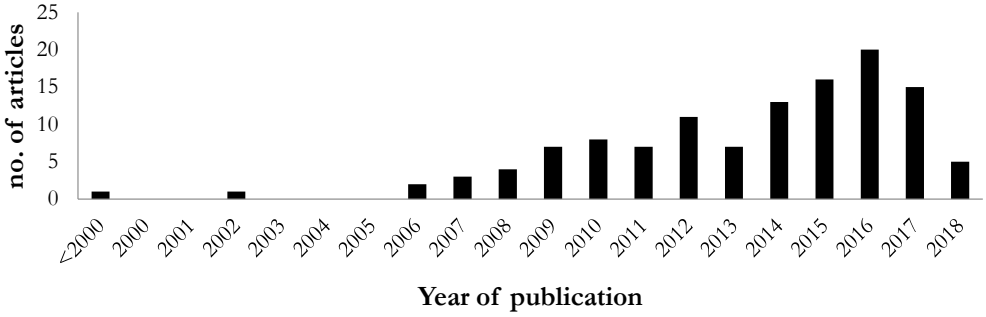
Supplementary

Supplementary A | The used literature search term combinations.

Spaced [ti]		Learning [ti]		Spaced learning [tw]		Health professions education [tw]
Spaced	AND	Learning	OR	Spaced training	AND	Education, Professional [Mesh]
Spacing		Memory		Spacing training		Medical educat*
Retriev*		Training		Spaced learning		Professional educat*
Repetition*		Educat*		Spacing learning		Teach*
Recall				Spaced interval training		Medical student*
Mental recall [Mesh]				Spaced interval learning		Biomedical student*
				Memory training		Pharmacy student*
				Spaced retrieval		Biology student*
				Spaced retrieving		Dental student*
				Retrieval practic*		Nursing student*
				Mass learning		Undergraduate*
				Massed learning		Graduat*
				Spacing effect		Intern*
				Distributed practic*		University
				Spacing efficacy		Universities
				Spacing practice sessions		Resident*
				Spacing of learning		Health professional*
				Spacing repetition		
				Spacing and repetition		
				Spaced educat*		
				Spaced test*		
				Test-enhaned learning		
				Testing effect*		

Within each column all terms are searched with the Boolean operator "OR".

Supplementary B | Frequency distribution of research articles on spaced learning included in this scoping review (*N* = 120). Articles are sorted by year.



Supplementary C | Characteristics of included research articles. Except for study location, characteristics were described for original research articles only (*n* = 103).

Characteristic	No. (%)
Study location	
United States	76 (63)
Europe	25 (20)
Canada	8 (7)
Australia	7 (6)
Asia	2 (2)
South America	2 (2)
Study population*	
Medical students	38 (32)
Residents	27 (23)
Other healthcare majors *pharmacy, dental, biomedical sciences, health sciences and prehealthcare*	18 (15)
Other healthcare professions *fellows, physician assistants, nurses, flight paramedics, family doctors, clinicians, program faculty and program directors*	18 (15)
Physicians	9 (8)
Educational content	
Knowledge *factual, conceptual, procedural*	74 (72)
Skills	27 (26)
N.A.	4 (4)
Domain	
Clinical	66 (64)
Basic sciences	9 (9)
Miscellaneous	28 (27)
Subject	
Medical specialties	60 (58)
Guidelines, principles, quality control	11 (11)
Anatomy	7 (7)
Physiology	5 (5)
Molecular biology	3 (3)
Dental education	2 (2)
Miscellaneous *Teaching, Statistics, Nutrition, Resuscitation, Pain-assessment, Physical examination, Sex, Cognitive Behaviour Therapy*	15 (15)

**Some studies included multiple study populations.*

Supplementary D | Extended overview of spaced learning terms.

Terms used without definitions
Spaced testing
Spaced instruction
Spaced training
Dispersed learning
Distributed learning
Spaced retrieval practice
Spaced studying
Repeated retrieval practice

Terms with single definition	Definitions
Spaced distribution	Educational encounters that are repeated over spaced time intervals.
Repeated practice	Practice is distributed over several sessions rather than massed as a single block of training.
Spaced approach	Distribution of a fixed amount of teaching hours over a longer time period.
Spaced repetition	A learning approach that focuses on reviewing content multiple times over optimized time intervals.
Automated spaced repetition	The observation that it is easier to remember information when it is studied multiple times over a long time span, rather than studied once or a few times in a short time span.
Structured spaced training	Spaced training; in which training is undertaken with breaks.
Interleaved practice	to structure the acquisition of multiple learning sets such that learning alternates between sets.
Distributed training	A practice schedule in which periods of training are interspersed with rest periods.
Distributed method of learning	instead of learning a French word by continuously reading it off a flashcard, one could memorize it over days or weeks from different sources, for example, by reading newspapers, perusing restaurant menus, and hearing it in conversation.
Space repetition learning	Providing small modules of information to learners over time to overcome the normal forgetting that occurs.

Repeated testing	People learn and retain information better through repeated exposure. Actively retrieving content during a test strengthens retention even more.
Distributed study	Break the material up into smaller portions that are studied over a period of days. A distributed study strategy is more effective when it includes repetition, with topics being re-visited, so as to reinforce learning.
Interactive spaced education	Interactive spaced education (ISE) is an online education system which harnesses the spacing effect, the psychological finding that educational material which is repeatedly presented over spaced intervals is learned and retained more efficiently.
Spaced training	Spaced training involves distributing learning tasks and skill acquisition practice sessions over a specified time interval, whereas massed practice occurs over the course of 1 or 2 intense and content-heavy sessions.
Interval learning	Learning over time. Seeing the presentation of new materials over time, in bite-sized chunks, and then seeing them again at a later time, particularly as a test.
Interval training	Learners practice multiple times for shorter periods in interval training.

Terms with plural definitions	**Definitions**
#1 Spaced practice	Distributing practice over time
#2 Spaced practice	Creating a study schedule that spreads study activities out over time. The same amount of repeated studying of the same information spaced out over time will lead to greater retention of that information in the long run, compared with repeated studying of the same information for the same amount of time in one study session.
#1 Spaced learning	delivery of brief morsels of information repeated over time intervals, in contrast to massed learning, a bolus of information delivered all at once without breaks
#2 Spaced learning	Spaced learning is based on the temporal pattern of stimuli for creating long-term memories. It consists of blocks with highly condensed content that is repeated three times and interrupted by 10–20 min breaks during which distractor activities such as physical activity are performed.

#3 Spaced learning	Learning encounters that are ‘‘spaced’’ and ‘‘repeated over time’’. Spaced learning differs significantly from other pedagogies because it ‘‘pushes’’ short clinical casebased scenarios that take less than 5 minutes to consider to participants’ e-mail or hand-held mobile device.
#4 Spaced learning	Spaced learning fosters retention effects by a careful adjustment (increasing) of time-intervals between test repetitions.
#5 Spaced learning	The insertion of distinct temporal gaps between learning episodes. This is in contrast to massed learning, which refers to learning with little or no time between learning sessions.
#1 Retrieval practice	Retrieval practice involves internally recalling previously learned information as opposed to rereading or relistening to information that was previously seen or heard.
#2 Retrieval practice	Being tested, pimped, or otherwise asked to exhibit knowledge to which one has been previously exposed.
#3 Retrieval practice	In retrieval practice, testing is used as a method of teaching rather than a method of assessment.
#4 Retrieval practice	Testing. There are greater gains to be realized with repetition of retrieval practice distributed over longer intervals and interleaved with demands for recall of other concepts or skills.
#5 Retrieval practice	“how” one spends time while learning is relevant to the learning science strategy, in contrast to “when” (distributed learning).
#6 Retrieval practice	Bringing learned information to mind from long-term memory.
#1 Distributed practice	Practice sessions spaced in time.
#2 Distributed practice	Practice is distributed over several sessions rather than massed as a single block of training.
#3 Distributed practice	Scheduled educational sessions of learning and training interspersed with rest periods. Massed practice refers to a continuous block of training without rest.
#4 Distributed practice	Refers to a schedule where periods of practice are interspersed with periods of rest.
#5 Distributed practice	Study activities with intervals.

#6 Distributed practice	Distributed practice refers to spacing out ones' practice or relearning materials intermittently over time, whereas massed practice refers to learning materials in one long session that often occurs immediately prior to a learning assessment, e.g. cramming.
#7 Distributed practice	Practice interspersed with periods of rest.
#8 Distributed practice	Content and understanding of concepts is improved when study is spaced or distributed over a period of time, compared to cramming or massed practice.
#9 Distributed practice	A practice regime in which periods of training are interspersed with rest periods.
#10 Distributed practice	Knowledge or a skill is taught in multiple sessions separated in time.
#11 Distributed practice	Material learnt in brief training workshops decays quickly over time, whereas repetition on many occasions ensures greater retention.
#12 Distributed practice	Training in multiple sessions with different intervals.
#13 Distributed practice	Several training sessions.
#14 Distributed practice	Practice sessions being distributed in time with each session consisting of repeated practice of the exact same procedure. Distribution of practice can refer both to distribution of content into several lessons and to practice sessions being spaced by time, often days or weeks, and is also termed (time) spaced or interval training.
#15 Distributed practice	Learning spread over a period of time. Theoretically, teaching in small proportions dispersed over time is better with respect to knowledge and skill retention compared with massed delivery.
#16 Distributed practice	Practice sessions are distributed, either as massed or regular teaching sessions.
#17 Distributed practice	Involving smaller practice sessions with large interspersed rest periods.
#18 Distributed practice	Spacing out of multiple study or practice sessions over an extended period of time.
#19 Distributed practice	Creating a study schedule that spreads study activities out over time. The same amount of repeated studying of the same information spaced out over time will lead to greater retention of that information in the long run, compared with repeated studying of the same information for the same amount of time in one study session.
#1 Spaced education	The planned repeating of educational encounters over time to enhance knowledge retention.

#2 Spaced education	Spaced education involves spaced repetition of question based educational content, but also includes an adaptive rescheduling algorithm combined with compelling game mechanics.
#3 Spaced education	Spaced education is a teaching strategy that delivers educational content electronically over several weeks or months (spaced in time) in a case-based or quiz format.
#4 Spaced education	Improved knowledge retention when material is repeated at spaced intervals.
#5 Spaced education	The spacing effect is based on the idea of repeating information over spaced intervals of time compared with complete presentation at one time.
#6 Spaced education	Online learning that has been demonstrated to increase knowledge retention and impact on behaviour. SE involves participants receiving short multiple-choice questions and feedback via e-mail in a repeating pattern over a number of weeks.
#7 Spaced education	Online educational programs that are structured to take advantage of the pedagogical benefits of the spacing effect
#8 Spaced education	On-line spaced education programs attempt to improve knowledge retention by harnessing the pedagogical merits of the spacing effect.
#9 Spaced education	SPACED education is a novel form of online education based on the 2 core psychology research findings of spacing and testing effects.
#10 Spaced education	Online educational programs that are structured to take advantage of the pedagogical benefits of the 'spacing effect'.
#11 Spaced education	Educational programs that are constructed to take advantage of the pedagogical merits of the spacing effect
#12 Spaced education	The psychologic finding that training or educational material that is spaced and repeated over time (spaced distribution) results in greater knowledge acquisition and retention of content than when the same material is presented at a single time point (mass distribution).
#13 Spaced education	Educational content delivered in small quantities and repeated over time, through electronic distribution
#14 Spaced education	A conceptual educational framework that relies on the delivery of succinct pieces of information related to a specific content area spaced out over time.

#15 Spaced education	Involves participants' receiving short multiple-choice questions and feedback via e-mail in a repeating pattern over a number of weeks.
#16 Spaced education	Online educational programs that are structured to take advantage of the pedagogical benefits of the spacing effect, in which periodically repeated, educational encounters lead to improved knowledge attainment and retention compared with a single "bolus" educational opportunity.
#17 Spaced education	An elearning platform in which "information" is presented and repeated over spaced intervals and is learned and retained more effectively.
#18 Spaced education	Educational encounters are spaced and repeated over a defined period.
#19 Spaced education	A web-based, student-directed learning tool.

Supplementary E | Retention-test test analyses.

	Mean	SD
Total score (points)	9.55	3.82
Total score (%)	32.94	13.18
KR-20 alpha	0.74	
Question nr.	p-value	Rir
Question 1	0.00	0.00
Question 2	0.11	0.46
Question 3	0.65	0.20
Question 4	NA	NA
Question 5	0.88	0.33
Question 6	0.88	0.17
Question 7	0.61	0.27
Question 8	0.34	0.38
Question 9	0.04	0.16
Question 10	0.07	0.07
Question 11	0.05	0.36
Question 12	0.88	0.22
Question 13	0.28	0.36
Question 14	0.03	0.27
Question 15	0.06	0.11
Question 16	0.36	0.25
Question 17	0.19	0.25
Question 18	0.66	0.27
Question 19	0.52	0.39
Question 20	0.28	0.28
Question 21	0.11	0.40
Question 22	0.05	0.32
Question 23	0.89	0.34
Question 24	0.14	0.24
Question 25	0.36	0.27
Question 26	0.43	0.33
Question 27	0.22	0.07
Question 28	0.04	-0.09
Question 29	0.50	0.30
Question 30	0.25	0.23

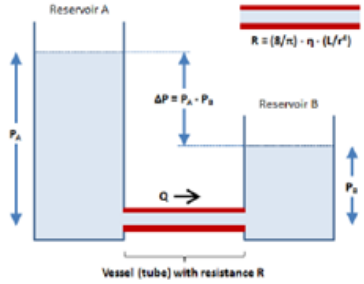
Supplementary F | Information sheet included in the study protocol (Dutch).

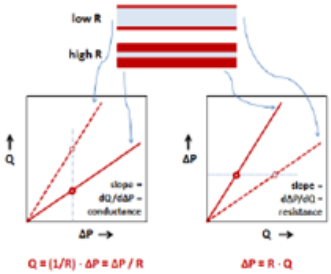
BEGRIPPEN en FORMULES

De figuren op dit blad illustreren de begrippen weerstand en compliantie, je krijgt nu een aantal vragen over deze begrippen. Je mag dit blad bij het beantwoorden van de vragen blijven raadplegen. Gebruik de achterkant als notitieblad. Je hoeft dit blad niet in te leveren. Neem nu eerst 2 minuten om dit blad nogmaals te bestuderen.

Weerstand karakteriseert de relatie tussen drukval en stroming door een vat (buis).
Drukval is het verschil in druk tussen begin en eind van het vat.

R weerstand
ΔP drukval = driving pressure
Q stroming = flow

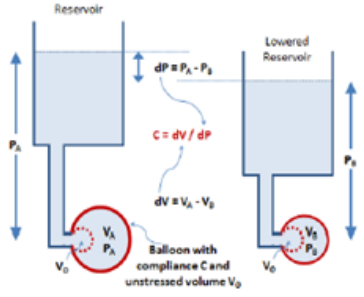


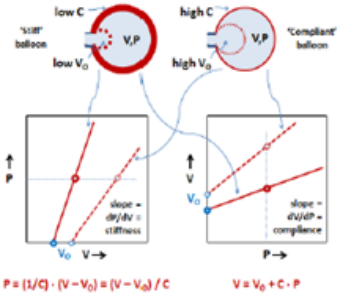


In de medische fysiologie wordt voor druk meestal de eenheid mmHg gebruikt en voor stroming ml/s.
De eenheid voor weerstand is dan dus mmHg/(ml/s).
Maar soms worden ook andere eenheden gebruikt, zoals cmH_2O voor druk en L/min voor stroming. In dat geval wordt de eenheid voor weerstand cmH_2O/(L/min)
NB: weerstand = 1/geleiding ofwel resistance = 1/conductance

Compliantie karakteriseert, samen met het unstressed volume, de relatie tussen druk (transmurale druk) en volume van een compartiment (ballon).
Transmurale druk is het verschil in druk tussen binnen en buiten het compartiment.
'Unstressed volume' is het volume waarmee het compartiment gevuld kan worden, zonder dat de wand opgerekt wordt en dus zonder dat de druk gaat stijgen (volume bij druk = 0).

C compliantie
V_o unstressed volume
P druk
V volume





In de medische fysiologie wordt voor druk meestal de eenheid mmHg gebruikt en voor volume (en voor unstressed volume) ml. De eenheid voor compliantie is dus ml/mmHg.
NB: compliantie = 1/stijfheid = 1/elastantie (dus lage compliantie = hoge stijfheid)

Supplementary G | Clusters significantly more activated in understanders and misunderstanders.

Group	Condition	Region	MNI coordinates (x; y; z, mm)	Cluster size (voxels)	Cluster P
Understanders	Scientific conception	R middle temporal area (BA21)	62;-34;-14	26334	.0004
		R supplementary motor area (BA6)	60;-4;46		
		R anterior cingulate cortex (BA32)	6;-4;46		
		L anterior cingulate cortex (BA24)	-6;-8;46		
		R superior parietal lobe/precuneus (BA7)	26;-56;45		
		R putamen (BA49)	38;-2;-2	3461	.0204
		R supplementary motor area (BA6)	64;8;16		
		R inferior frontal gyrus (BA44)	62;12;14		
		R inferior temporal gyrus (BA37)	38;-50;-22	2502	.0338
	Misconception	L anterior cingulate cortex (BA32)	-8;14;34	27720	.0002
		R superior parietal lobe/precuneus (BA7)	8;-76;50		
		L superior parietal lobe/precuneus (BA7)	-20;-70;50		
		R ventrolateral prefrontal cortex (BA47)	34;30;-22	3349	.0172
		R inferior frontal gyrus (BA44)	52;8;-2		
		R anterior prefrontal cortex (BA10)	28;54;-18		
	Positive control	R inferior temporal gyrus (BA37)	32;-40;-24	32120	.0002
		R anterior cingulate cortex (BA32)	8;8;34		
		R inferior frontal gyrus (BA44)	62;12;14		
		L inferior parietal lobe (BA40)	-38;-38;48		
		L transverse temporal area (BA41)	-40;-26;10		
		R thalamus (BA50)	16;-16;8		

	Negative control	R inferior temporal gyrus (BA37)	38;-42;-24	31446	.0002
		R anterior cingulate cortex (BA24)	-8;0;42		
		L inferior parietal lobe (BA40)	-44;-32;12		
		R inferior frontal gyrus (BA44)	60;14;10		
		L transverse temporal area (BA41)	-48;-20;10		
		L anterior prefrontal cortex (BA10)	-23;59;-14		
		R ventrolateral prefrontal cortex (BA47)	-26;18;-20		
Misunderstanders	Scientific conception	R supplementary motor area (BA6)	62;8;4	65211	.0002
		L supplementary motor area (BA6)	-54;-4;40		
		R inferior temporal gyrus (BA37)	52;-54;6		
		R anterior cingulate cortex (BA24)	8;0;42		
		L dorsolateral prefrontal cortex (BA9)	-38;37;29		
		R inferior frontal gyrus (BA44)	60;14;10		
	Misconception	R inferior temporal gyrus (BA37)	26;-32;26	74691	.0002
		R angular gyrus (BA39)	40;-64;42		
		R visual association area (BA18)	2;-80;-6		
		R superior temporal gyrus (BA22)	54;2;-6		
		R anterior cingulate cortex (BA24)	8;0;42		
		R dorsolateral prefrontal cortex (BA9)	34;38;29		
		R inferior frontal gyrus (BA44)	60;14;10		
	Positive control	R inferior temporal gyrus (BA37)	30;-42;-24	67524	.0002
		R transverse temporal area (BA41)	40;-32;10		
		L superior parietal lobe/precuneus (BA7)	-24;-46;52		
		R superior temporal gyrus (BA22)	64;-42;16		
		R anterior cingulate cortex (BA32)	8;3;42		
		L dorsolateral prefrontal cortex (BA9)	-38;37;29		
		R inferior frontal gyrus (BA44)	60;14;10		

	Negative control	R inferior temporal gyrus (BA37) R anterior cingulate cortex (BA32) R inferior parietal lobe (BA40) R medial prefrontal cortex (BA8) L anterior prefrontal cortex (BA10) L angular gyrus (BA39) R thalamus (BA50) L dorsolateral prefrontal cortex (BA9) R inferior frontal gyrus (BA44)	38;-42;-24 8;3;42 50;-28;32 12;20;32 -28;50;-11 -28;-60;34 16;-14;2 -38;37;29 60;14;10	65573	.0002
Misunderstanders > Understanders	Scientific conception	L putamen (BA49)	-24; -8; -28	1163	.0024
	Misconception	L putamen (BA49)	-34;-6;-10	703	.0068

Cluster-defining threshold p < .001, cluster extent threshold p < .05, FWE corrected (random effect analysis). Z-max for all clusters: 3.54. Coordinates are based on the most significant voxel in the cluster.

Supplementary H | Clusters significantly more activated in a certain comparison of conditions.

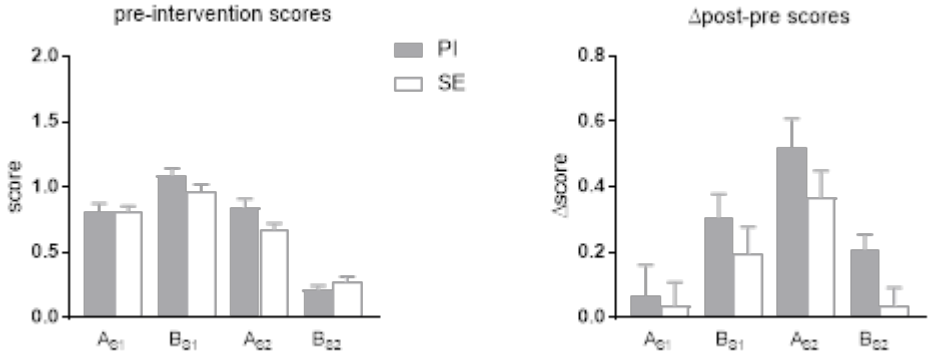
Group	Condition	Region	MNI coordinates (x; y; z, mm)	Cluster size (voxels)	Cluster P
Understanders	Scientific conception > Positive control	L inferior parietal lobe (BA40)	-38;-40;38	4088	.0006
		R superior parietal lobe/precuneus (BA7)	26;-64;42		
		L superior parietal lobe/precuneus (BA7)	-18;-70;52		
	Scientific conception > Negative control	R visual association area (BA18)	38;-92;18	3768	.0004
		R superior parietal lobe/precuneus (BA7)	26;-58;62		
		L superior parietal lobe/precuneus (BA7)	-30;-58;60		
		R occipito-temporal cortex (BA19)	38;-82;18		
	Misconception > Positive control	L inferior parietal lobe (BA40)	-42;-44;48	2738	.0006
		L superior parietal lobe/precuneus (BA7)	-20;-72;50		
		L postcentral gyrus (BA1)	-50;-34;52		
		R superior parietal lobe/precuneus (BA7)	22;-66;48	1849	.0018
		R angular gyrus (BA39)	46;-60;38		
		R inferior parietal lobe (BA40)	44;-52;52		
		L orbitofrontal cortex (BA11)	-8;50;-18	610	.0414
		L ventrolateral prefrontal cortex (BA47)	-50;42;-16		
	Misconception > Negative control	L superior parietal lobe/precuneus (BA7)	-18;-72;50	2717	.0002
		R superior parietal lobe/precuneus (BA7)	18;-70;52		

	Negative control > Positive control	R orbitofrontal cortex (BA11)	20; 38; -16	1446	.0040
		R ventrolateral prefrontal cortex (BA47)	36;44;-16		
		R anterior prefrontal cortex (BA10)	38; 56; -14		
		L anterior prefrontal cortex (BA10)	-26;56;-14		
		R angular gyrus (BA39)	46;-58;32	1147	.0058
		R inferior parietal lobe (BA40)	44;-48;44		
		L anterior temporal lobe (BA38)	-42;14;-36	764	.0140
		L middle temporal gyrus (BA21)	-56;-6;-22		
					.0180
		L angular gyrus (BA39)	-44;-60;46	658	
		L inferior parietal lobe (BA40)	-48;-40;40		
					.0274
		R inferior temporal gyrus (BA37)	66;-48;-14	542	
		R middle temporal gyrus (BA21)	64;-40;-10		
Misunderstanders	Scientific conception > Positive control	L inferior parietal lobe (BA40)	-64; -28; 42	5657	.0006
		L superior parietal lobe/precuneus (BA7)	-36; -58; 64		
		R superior parietal lobe/precuneus (BA7)	18; -66; 60		
		L postcentral gyrus (BA1)	-48; -32; 58		
	Scientific conception > Negative control	L visual association area (BA18)	-26; -82; 0	4101	.0002
		L superior parietal lobe/precuneus (BA7)	-22; -66; 58		
		R superior parietal lobe/precuneus (BA7)	22; -68; 58		
		R visual association area (BA18)	34; -84; 6	1612	.0108

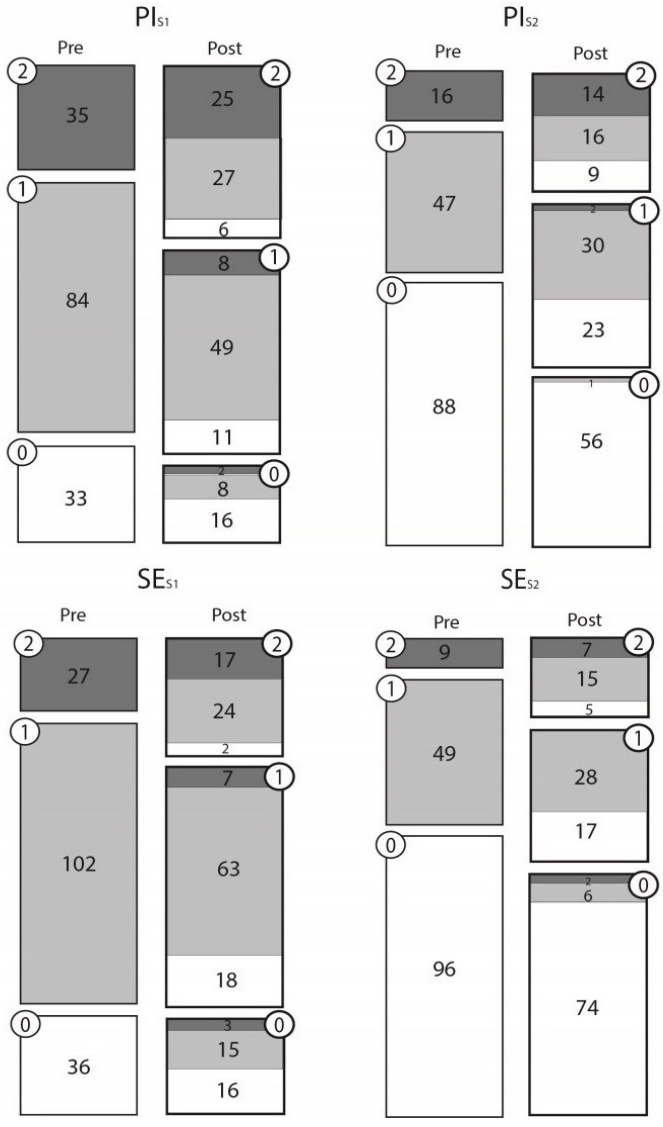
Misconception > Positive control	R inferior temporal gyrus (BA37)	54; -54; -14	14729	.0002
	L visual association area (BA18)	-24; -86; 0		
	R visual association area (BA18)	36; -84; 0		
	L superior parietal lobe/precuneus (BA7)	-16; -68; 54		
	L occipito-temporal cortex (BA19)	-44; -78; -14		
Misconception > Negative control	R visual association area (BA18)	16; -98; -10	10352	.0002
	R occipito-temporal cortex (BA19)	40; -84; 24		
	R superior parietal lobe/precuneus (BA7)	24; -68; 52		
	L superior parietal lobe/precuneus (BA7)	22; -66; 54		
Negative control > Positive control	L inferior parietal lobe (BA40)	-46; -40; 50	1768	.0022
	L superior parietal lobe/precuneus (BA7)	-30; -62; 38		
	L angular gyrus (BA39)	-40; -50; 36		
Misconception > Scientific conception	L angular gyrus (BA39)	-38; -66; 38	1103	.0132
	R visual association area (BA18)	38; -86; -4	1010	.0174
	L inferior temporal gyrus (BA37)	-66; -40 ;-16	876	.0244
	L middle temporal area (BA21)	-70; -28; -8		

Cluster-defining threshold p < .001, cluster extent threshold p < .05, FWE corrected (random effect analysis). Z-max for all clusters: 3.54. Coordinates are based on the most significant voxel in the cluster.

Supplementary I | Pre-test scores on conceptual problems in seminars 1 and 2. Pre-post scores were examined separately for all four questions (two concepts in two seminars) to assess if efficacy of active learning was consistent among these exercises. Average pre scores are shown for PI and SE groups (left panel). Lowest scores were found for exercise B_{s2}. The relative change in scores was positive for all exercises in both SE and PI groups, with higher gains for PI in all cases (right panel). Accordingly, a significant increase of 0.17 was found on exercise B_{s2} scores in the second seminar between PI and SE groups ($t(151)=3.206$, $p = .023$). The highest performance gains for single exercises were observed in the PI condition, showing the largest increase of 0.52±0.09 for A_{s2}.



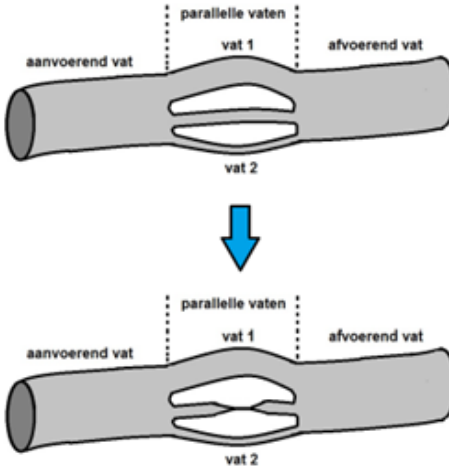
Supplementary J | Students' individual scores on conceptual problems before and after intervention. The conceptual problems consisted of two related questions each yielding 1 point, thus a maximal score of 2. This scheme shows the distribution of total scores pre and post intervention for all students participating in the protocol. The total scores (0, 1 or 2 points) are indicated in the circles. The white, grey and dark areas indicate, respectively, students with a pre-test score of 0, 1 or 2 points. The numbers in the bars indicate the number of students with a specific score. Data for both seminars is depicted separately to illustrate the difference in difficulty level between the seminars. Seminar 2 had more students with score 0 and fewer with scores 1 or 2, but similar shifts towards higher scores post intervention.



Supplementary K | Multi-tier question (in Dutch) with 3-tiers: Yes/No, Explanation, and Confidence.

Vraagstuk 2

Een chirurg ziet in het onderbeen van een patiënt deze vaatstructuur: drie parallelle vaten met een aanvoerend en een afvoerend vat. De flow door vat 1 is het dubbele van de flow door vat 2.



Dan klemt de chirurg het middelste vat af waardoor er geen flow meer door dat vat gaat. De chirurg beweert dat de flow door vat 1 nog steeds het dubbele is van de flow door vat 2. Je mag aannemen dat de diameters van vat 1 en vat 2 niet veranderen.

Heeft de chirurg gelijk?

- ☐ Ja
- ☐ Nee

Wat is de beste verklaring of het belangrijkste argument voor je antwoord?

- ☐ Omdat de flow verdeling bepaald wordt door de verhouding van de weerstanden
- ☐ Omdat de flow via het vat met de laagste weerstand gaat
- ☐ Omdat de totale flow constant blijft
- ☐ Omdat de totale weerstand toeneemt en dus de flow in beide vaten evenveel afneemt

Hoe zeker ben je dat je antwoord inclusief verklaring correct is?

☐	☐	☐	☐	☐
Heel onzeker (was gok)	Vrij onzeker	Ik twijfel	Vrij zeker	Heel zeker (bijna 100%)

Supplementary L | Refutation text (in Dutch) with a refutation element, correct answer, and explanation.

Sommige mensen zeggen dat de flow de weg van de minste weerstand kiest en dat dus de flow die na het afklemmen niet meer door het middelste vat kan, door vat 1 zal gaan. Dat is niet correct omdat flow niet via de weg van de minste weerstand gaat, maar zich verdeelt afhankelijk van de weerstanden. Het vat met de laagste weerstand krijgt de meeste flow, maar ook een vat met een hogere weerstand krijgt flow.

Het juiste antwoord is:
Ja, de chirurg heeft gelijk, omdat de flow verdeling tussen vat 1 en vat 2 bepaald wordt door de verhouding van de weerstanden (en die is niet veranderd).

De drukval is voor alle parallelle vaten hetzelfde. Flow is drukval/weerstand, dus de verhouding tussen de flows wordt bepaald door de verhouding tussen de weerstanden: het vat met de laagste weerstand krijgt de meeste flow. Omdat vooraf de flow in vat 1 het dubbele is van de flow door vat 2 is dus blijkbaar de weerstand van vat 1 de helft van de weerstand van vat 2. Nadat het middelste vat is afgeklemd verandert wellicht de drukval, maar deze is wel nog steeds voor alle parallelle vaten gelijk. De weerstanden van vat 1 en 2 blijven hetzelfde, dus ook hun verhouding. En dus gaat er nog steeds tweemaal zoveel flow door vat 1 als door vat 2.
Wellicht neemt de flow door vat 1 toe, maar dat is dan ook voor vat 2 het geval. Echter de toename in vat 2 is maar de helft van de toename in vat 1, omdat de weerstand van vat 2 tweemaal zo hoog is als van vat 1. Hoewel dus beide flows kunnen veranderen, blijft de verhouding tussen de twee flows hetzelfde.

Supplementary M | Interview guide.

Evaluating the thinking aloud assignments

What was your experience with doing these assignments?

- o How come?
- o How did you feel?
- o Which parts did you find easy/difficult?
- o How did you estimate your confidence after finishing an assignment?

Metacognitive knowledge

Where do you start when you get such conceptual assignments?

- o What do you do when you do not understand the assignment, or part of the assignment?
- o Is the assignment finished the moment you write down your answer?
- o Can you tell me what you do afterwards?

Do you use specific strategies while solving this type of assignments?

- o Does such a strategy depend on the type of question? How?
- o Did you ever change strategies for different types of questions? Why?

Can you tell me what you strenghts and weaknesses are regarding solving this type of conceptual assignments?

Metacognition in the curriculum

Can you describe any situations or name ways through which you obtain insight in how well you understand something?

If we would improve the curriculum in such a way that it becomes easier for you to estimate how well you understanding something, does that have added value for you?

- o How do you think we should improve the curriculum?

Supplementary N | Template thinking aloud and interview.

Metacognitive experiences

MAIN THEME	SUB THEME	EXAMPLE
Feeling of knowing		'Eureka.' 'I do not think so, but I do not know why.' 'Intuitively, or based on my feeling it has to be.. maybe I have the feeling I am making a mistake.'
Feeling of familiarity		'Yes, I recognise this image. I think I have seen this before.' 'I recognise this from year 1.'
Feeling of confidence	Sure	'I am quite sure about this.'
	Unsure	'Yes. No. I am not quite sure.'
	Doubting	'Yes, now I start doubting.'
Feeling of difficulty		'O god, this is difficult.' 'O yes, I was afraid of this [type of exercise] already.'

Metacognitive skills

MAIN THEME	SUB THEME	EXAMPLE
Planning	Allocating resources	'I will start by reading the formulas.'
	Identifying problem	'OK, so it is about...'
	Creating overview	'I will write that down for now.. so I have an overview.'
Monitoring	Rereading	Rereading a paragraph.
	Summarising	'I will write summarise this because I might need it later.'

Eliminating	‘So then we have the option left..’ ‘So this one can be eliminated for sure..’
Selecting new source	Allocates a new resourse, e.g. formula sheet, halfway through the assignment.
Using mnemonic	Using a mnemonic to explain the situation in layman language.
Using numbers	‘OK, so for example, we fill in numbers here..’
Using visuals	‘Let’s have a look. There is an image here.’
Using answer options	‘OK, I will read the answer options, because that might help me figure it out..’
Switching strategy	‘I now see that..’
Identifying adequacy of information	‘ Hm, this formula is not useful at the moment.’
Self-questioning	‘Is this right what I am saying?’
Goal-checking	‘What was the problem again?’
Self-explanation	Explaining to him/herself why the answer is incorrect/correct before committing to an answer.
Goal-free search	‘Maybe it has something to do with..’
Goal-directed search	‘I will search in the formula sheet for resistance, flow and pressure difference.’

	Judgement of learning	'These [the answer options] are all not the same compared to my answer. Then I have to look again. Maybe I am wrong.' 'I will just make a decision based on what sounds logical.. and based on what I remembered, not based on the reasoning and the process behind it'.
Evaluation	Checking answer	' I will just check everything again, because..'
	Elaborating on confidence	'So if the resistance decreases, so.. yes I am very sure about my answer.'

Metacognitive knowledge

MAIN THEME	SUBTHEME
Of self	Formulas/numbers
	Visual representation
	Speed of reasoning
	Not thinking 'straight'
	Insecurity
	Lack of knowledge/brainpower
	Compensating weaknesses
	Influence of environment
	Easy
	Overview of the stiutation
	Abstract thinking
	Estimating
Of Task	Different strategies for figures/formulas
	Different strategies for facts/cooncepts
Of Strategy	Not aware of strategy
	Eliminating options
	Using visual representation
	Highliting
	Thinking out loud

	Identifying the problem
	Goal-checking
	Checking previous assumptions
	Good reading
	Using numbers
	Creating overview
	Filling in formulas
	Tackle the problem from different angles
	Evaluating
Cues for confidence	Feeling
	Time
	Familiarity/previous experiences
	Reasoning
	Deduction
	Representation (figures/formulas)
	Combination of reasoning and feelings

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List of scientific contributions

Scientific articles

Versteeg, M., Hendriks, R. A., Thomas, A., Ommering, B. W. C., & Steendijk, P. (2020). Conceptualising spaced learning in health professions education: A scoping review. *Medical Education, 54*(3), 205-216.

Versteeg, M., & Steendijk, P. (2019). Putting post-decision wagering to the test: a measure of self-perceived knowledge in basic sciences? *Perspectives on Medical Education, 8*(1), 9-16.

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Timmer, M. C. J., Steendijk, P., Arend, S. M., & Versteeg, M. (2020). Making a lecture stick: the effect of spaced instruction on knowledge retention in medical education. *Medical Science Educator*, *30,* 1211-1219.

Versteeg M., van Loon M., Wijnen-Meijer M., & Steendijk P. Refuting misconceptions in medical physiology. *BMC Medical Education*, *20*(1), 1-9.

Versteeg M., Guusje B., Wijnen-Meijer M., Ommering B. W. C., de Beaufort A. J., Steendijk P. What were you thinking? Medical students' metacognition and perceptions of self-regulated learning. *Submitted*.

Versteeg M., & Steendijk P. The origins of medical students' misconceptions and misunderstandings in cardiovascular physiology. *Submitted*.

Versteeg M., Hafkemeijer A., de Beaufort A. J., & Steendijk P. An understanding of (mis)understanders: exploring the underlying mechanisms of concept learning using functional magnetic resonance imaging. *Submitted.*

Awards & nominations

2019	Spaced learning in het medisch onderwijs: een scoping review.	NVMO congress (nominated)
2018	Door de ogen van de student: misconcepties in het medisch fysiologisch onderwijs	NVMO congress (paper prize)
2018	Spaced learning in het medisch onderwijs: tijd voor een instructionele revolutie?	NVMO congress (poster prize)
2017	Actieve leerstrategieën voor toepassingen van fysiologische concepten in medisch onderwijs	NVMO congress (nominated)

Presentations

2020	Spaced learning in medical education: a scoping review	Cardiology research reports
2020	An understanding of misunderstanders	OEC research meeting
2019	Leren slim te leren. Meer aandacht voor metacognitie in medisch onderwijs	NVMO congress
2019	Spaced learning in het medisch onderwijs: een scoping review	NVMO congress
2019	Making a lecture stick: The effects of spaced instruction on knowledge retention in medical education	AMEE congress
2019	Informing the uninformed: students' misconceptions in cardiovascular physiology	Cardiology research reports
2018	Door de ogen van de student: misconcepties in het medisch fysiologisch onderwijs	NVMO congress
2018	Weet jij wat je (niet) weet? De Post-Decision Wagering methode als een maat voor zelfkennis	NVMO congress
2018	Through the lens of confidence: students' misconceptions in physiology	EARLI SIG 03 meeting
2018	Hoe ervaren geneeskunde studenten hun leeruitkomsten van de studie?	NVMO PhD day
2018	A typology of reviews	OEC research meeting
2018	Active learning strategies for comprehension and transfer of physiological concepts	Cardiology research reports
2017	Actieve leerstrategieën voor toepassingen van fysiologische concepten in medisch onderwijs	NVMO congress
2017	Evidence-based education in medical physiology	Rogano meeting
2017	An experimental approach to medical education	NVMO PhD day
2017	Contexts, concepts and cognition	OEC research meeting

Posters

2018	Spaced learning in het medisch onderwijs	NVMO congress
2018	Moving towards spaced learning in medical education: time to start an instructional revolution?	EARLI SIG 22 meeting
2016	Toepassing van 'peer discussion' tijdens werkgroep onderwijs	NVMO congress

(Invited) lectures

2020	Through the lens of confidence: students' misconceptions in physiology	Technical University of Munich & Leiden Institute of Advanced Computer Science
2020	Onderzoek van medisch onderwijs	LUMC Honours programme
2020	Leren slim te leren: meer aandacht voor metacognitie in medisch onderwijs	LUMC LEARN
2019	From bench to classroom: investigating concept learning in medical education	LUMC Groot Onderwijsoverleg
2019	Making a lecture stick: The effects of spaced instruction on knowledge retention in medical education	James Pickering visit
2019	Learning to learn	Law Faculty
2019	Onderzoek van onderwijs	Student Advies Commissie
2019	Zelfreguleren kun je leren: een (neuro) wetenschappelijke kijk op metacognitie	LUMC LEARN
2019	Education meets Neuroscience: implications for teaching and learning	Law Faculty
2019	Onderzoek van onderwijs	Board of Directors
2018	Misconcepties in het medisch fysiologisch onderwijs	LUMC programme committee
2018	Education meets Neuroscience: implications for teaching and learning	Leiden Faculty of Science & LUMC LEARN
2018	Insights on how neuroscience can change your teaching	Leiden Teachers Academy
2017	Simulations in Healthcare	Clinical Technology Bachelor
2017	Does 'Peer Instruction' enhance understanding and transfer of physiological concepts?	LUMC LEARN

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Curriculum Vitae

Marjolein Versteeg was born on the 12th of October 1994 in Hengelo, the Netherlands. After completing high school at Bataafs Lyceum in 2011, she received her bachelor's degree in Biomedical Sciences from Utrecht University in 2014. Because of her interest in neurobiology, Marjolein enrolled in the research master Neuroscience & Cognition. In 2016, she received her master's degree from Utrecht University. As part of her master's degree, Marjolein performed molecular biology research regarding neurodegenerative diseases at the Utrecht University Medical Center and Harvard University. Upon her return from the United States, Marjolein started her PhD research at Leiden University Medical Center under supervision of Prof.dr. Paul Steendijk. In her PhD project, Marjolein studied various learning processes from an educational neuroscience point of view. Over the years, she developed into a medical education researcher with knowledge about a broad range of educational research methods and methodologies. Her findings resulted in more insights in learning and instruction within the context of health professions education as described in this thesis. Besides her research activities, Marjolein was actively involved in the PhD network of the Dutch Association for Medical Education. In September 2020, Marjolein started a new job at VeiligheidNL, where she will continue working as a researcher.