The Learning Curriculum

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Introduction

As teacher educators, one important task is helping teachers to understand how students learn and to use this knowledge in their teaching. We have found recent syntheses, such as Deans for Impact's The Science of Learning (2015) and the Institute for Teaching's Learning: What is it, and how can we catalyse it? (2018) invaluable in articulating the principles of how students learn, and suggesting ways they can be applied in the classroom. Sharing these ideas with teachers has proved more challenging; we have struggled without a curriculum or sufficient guidance on how to teach the science of learning to teachers.

Specifically, we found ourselves asking:

- How should we sequence learning about these principles?
- How could we evidence and illustrate these principles accessibly yet defensibly?
- How could we check what teachers had understood?

The Learning Curriculum is the result of four months during which we have tried to answer these questions and tested our answers with our teachers. We are sharing what we have learned because we could not find answers to our questions recorded elsewhere. We do not pretend that this is the last word: no doubt there are better examples, studies and assessments available. However, we hope that this first draft will both provide a resource for teacher educators, and encourage them to improve upon our suggestions.

We are grateful to colleagues within the Institute for Teaching (IfT) for their support and suggestions, including Kyle Bailey, Emma Lark, Peps McCrea and especially Nick Rose. All errors remain our own.

We hope you find this useful, and look forward to improving it with your help.

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Structure of The Learning Curriculum

We debated how best to structure this curriculum: what is a logical sequence to share these ideas with teachers? What do teachers need to know to make sense of other principles?

We concluded that the structure which would best help teachers to apply these principles was a sequence of steps in planning a lesson. We recognise the limitations of this approach; an educational psychology course might adopt a different sequence, for example; and focusing on planning units is often more fruitful than planning lessons. However, we believe that the disadvantages are outweighed by the advantage of offering steps which are clear, familiar, and invite action directly.

Question

Each principle is introduced with a question which a teacher might ask themselves in planning a lesson.

Research summary

The research summary offers a clear, concise explanation of the evidence which underpins the principle we are suggesting.

Key study

Key studies are research studies to which teacher educators may wish to refer. We do not expect most teachers to have the time to read them, but we believe that encouraging teacher educators to refer to them may help to illustrate the principle concerned and offer a glimpse of the research underlying it.

Principle

Based on the research and the key studies, we articulate a principle.

Analogy (and limitations)

Analogies and metaphors often help to make complicated ideas clearer for learners. This section collects analogies we have found useful. We recognise that no metaphor perfectly reflects the idea it represents (just as no map perfectly coincides with a territory) and that analogies can distort learners’ understanding too, so we also suggest limitations to the analogy, which teacher educators may wish to highlight.

Applications

We suggest techniques that teachers may wish to use in the classroom which could put each principle into practice. We should stress that we offer these merely as examples, not because we are wedded to them and we recognise that a technique can be applied in many ways, some of which are true to a principle, some of which are not.

Assessment

Just as we check what students have understood, we may wish to check what teachers have understood. We have designed hinge questions which seek to elicit possible teacher misconceptions: each answer choice (except the correct one) incorporates a possible teacher misconception about the principle. We have given answers and explained the misconceptions beneath each question. These are our first attempts to create worthwhile questions, and we hope fellow teacher educators will test them and help us to improve them.

Key terms

We use the following terms throughout the document, with the following working definitions:

Working memory – the part of our memory which is active at any one time

Long-term memory – enduring memories

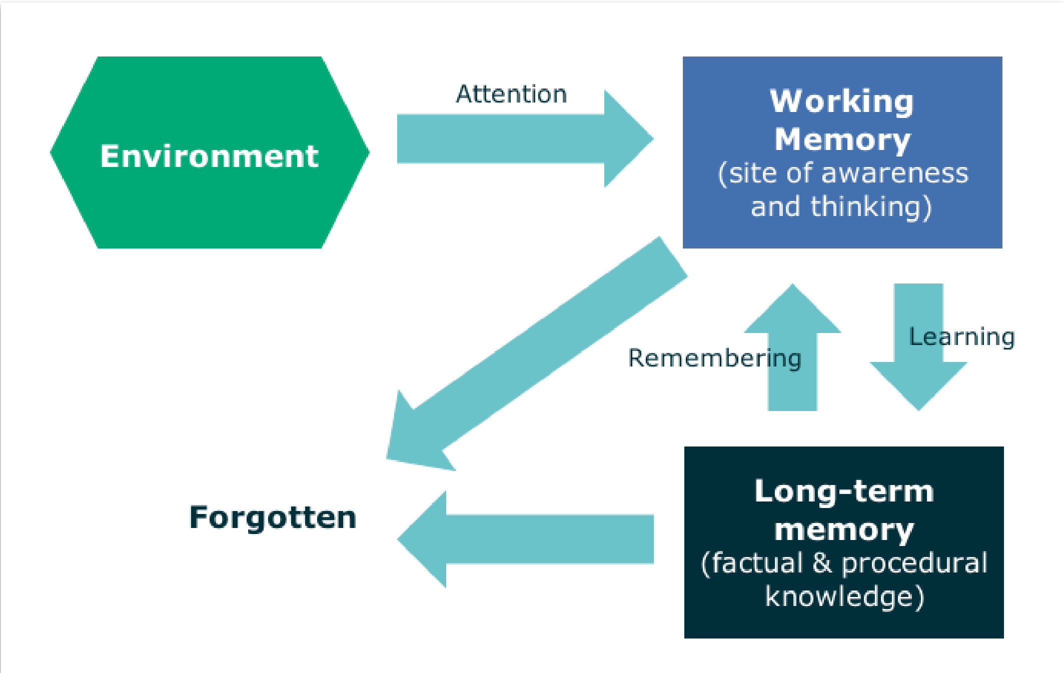
Learning – a change in knowledge and skill which is inferred at some point after teaching: for example, if a student remembers and uses the correct formula to find the area of a circle, one year after they were taught it, this is learning.

Performance – a change in knowledge and skill which can be observed and measured during teaching: for example, if a student uses the correct formula to find the area of a circle having just been taught to do so, this is performance, not learning.

Storage strength – a measure of whether information is deeply embedded or well learned, so is likely to be recalled later: for example, information has high storage strength if a student can recall it after a year without thinking about it.

Retrieval strength – a measure of how easily recalled something is in the current situation: for example, does the required formula come to mind when a student wishes to calculate the area of a circle.

It may be helpful to refer to the 'simple model of memory' (Willingham, 2009), shown below, throughout.



Adapted from Willingham (2009, p.55)

1. What do students already know?

As a teacher begins considering what to teach in the next lesson, they have existing information, such as the curriculum and unit plan. What other information will prove useful in designing and pitching the lesson?

Research summary

Willingham, D. (2006). How Knowledge Helps. American Educator. Spring.

Key studies

Recht and Leslie (1988) asked students to read a text about baseball. Students with high knowledge of baseball understood the text equally well whether they had high or low reading comprehension skills. Those with high reading ability but low knowledge of baseball did no better than those with low reading ability.

Recht, D. R. & Leslie, L. (1988). Effect of prior knowledge on good and poor readers' memory of text. Journal of Educational Psychology, 80, pp.16-20.

Chi, Glaser and Rees examined how novices and experts solve problems differently. Experts were able to sort physics problems according to their deep structure (for example, putting problems which deal with the conservation of energy together), while novices sorted them according to superficial features (putting problems involving inclined planes together). While novices are just as good at identifying key terms in the problems as experts, it is experts' knowledge base which allows them to sort and respond to problems effectively.

Chi, M., Glaser, R., and Rees, E. (1982). Expertise in problem solving. In Sternberg, R. (ed.), Advances in the Psychology of Human Intelligence, Erlbaum, Hillsdale, NJ, pp. 7-75

Principle

Prior knowledge determines what students can learn; learning is made easier when new knowledge is connected to existing knowledge.

Analogy (and limitations)

Before students learn to accurately pass a football, they need to learn to stop the ball dead at their feet.

When attending a hospital as a sick patient and, without asking you anything about what's happened previously or looking at your notes or asking you any questions, the doctor hands you a bottle of medicine, we are likely to be wary of the cure it offers.

Teaching students content divorced from their current knowledge base is like trying to build a sandcastle in mid-air: the sand will have nothing to stick to and will crumble.

New information is like a ship coming in to dock: if it is to dock successfully we need to choose the bollards to which it will be attached. (Limitations: ships are impermanent).

Learning new knowledge is like adding bricks when building a wall. If bricks are missing lower down the wall, the foundations are insecure and the wall will collapse. (Limitation: teacher is trying to build thirty walls simultaneously).

Applications

We can identify prior knowledge before the start of a unit or lesson to support planning and activate prior knowledge so students can link new ideas to existing knowledge.

- Pre-quizzing – asking students questions which will be answered in the topic or lesson – identifies prior knowledge for teachers and activates it for students.

We can sequence teaching so that each lesson builds on previous lessons.

We can plan to help students build the foundational knowledge they need for success in a subject or topic (for example, times tables in maths; understanding the plot in order to analyse character in literature).

Assessment

Question When can our planning disregard student prior knowledge?

A. If students lack any prior knowledge of the topic.

B. If students' prior knowledge is likely to be substantially incorrect.

C. Students' prior knowledge will always affect what they can learn.

Answer & Explanation A is incorrect because students will always have some relevant prior knowledge, either from their own lives, or from past learning. B is incorrect because if students' prior knowledge is substantially incorrect this is particularly important for our planning. C is correct, students' prior knowledge will always affect what they can learn so we can never disregard student prior knowledge in our planning.

2. What can I teach students in this time period?

Once we ascertain what students currently know, we need to decide what they can learn during the lesson.

Research summary

[Centre for Education Statistics and Evaluation. (2017). Cognitive load theory: Research that teachers really need to understand. New South Wales Department of Education.]

Key study

An early study divided students into two groups: they approached the same trigonometry problems with different goals:

- Group A were given a specific goal (find the length of a particular line)
- Group B were not given a specific goal (find the length of any lines you can)

As they were solving identical problems, Group A might be expected to do better, since they had clearer instructions. In fact, students in Group A endured greater cognitive load, because they had to keep in mind numerous ideas which did not help them think about the trigonometry itself: what they were trying to find, what they had already found and what they needed to find next. Students in Group B remembered more about the problems – they learned more; whereas for students in Group A: "The cognitive-processing capacity needed to handle this information may be of such a magnitude as to leave little for schema acquisition, even if the problem is solved (p.261)."

Sweller, J (1988) Cognitive load during problem solving: Effects on learning. Cognitive Science, 12, 257-285.

Principle

Students working memory capacity – what they can think about at any one time – is limited; we should ask students to focus on only a handful of chunks (ideas, processes or pieces of information) at any one time. (What constitutes a 'chunk' depends on the individual student's prior knowledge).

Analogy (and limitations)

The working memory is a tiny shed. If we try to fill it with too many elements at one time, we won't have space to work efficiently. (Limitation: working memory should go on somewhere).

We can think of working memory and the implications of overloading it by thinking about juggling. Most people can juggle 1 or 2 balls at once, but as we add a 3rd or 4th we will likely drop them all.

Working memory is a bottleneck (where long-term memory is the bottle): it can only permit a certain amount through at a time. (Limitation 1: it's not just a bottleneck, as working memory also performs conscious thought. Limitation 2: Even if the students successfully solve a problem where they are overloaded – and so appear to have learned effectively – they might not have built the schemas required for learning.

Working memory is like a rickety rope bridge between the two cliffs (Environment and Long Term Memory). If we try to overload the rope bridge, it may well collapse. Even if we force too many people to cross at once and they are (luckily) successful, they will be so traumatised once they've got to the other side that they won't be able to form social bonds. (Even if students perform when they are overloaded, they may still struggle to learn).

Working memory is like gathering shopping in our hands: once we have three objects, picking up another one requires us to put an existing object down.

Managing load is like the junk filter in an email inbox. A poor filter leads to the inbox being filled up with junk emails which distract from those important emails. A good filter means that junk is reduced and we can attend to those emails that are important.

Applications

- Design tasks which challenge students to think about a few key ideas at any one time. Limit the number of 'moving parts' you ask them to think about.
- Reduce the cognitive load of challenging tasks by breaking them down and asking students to focus on one step at a time.
- Offer worked examples and completion problems (partial-examples which students can complete) to allow students to focus on how problems can be solved and focus on one step at a time.
- Remove support gradually to encourage students to complete problems increasingly independently.

Assessment

Question Which of these is most likely to help students learn without overloading their working memory?

A. Focusing learning on ideas and concepts with which students are already familiar.

B. Breaking the content into smaller components.

C. Providing exciting resources like videos, artefacts.

Answer & Explanation A is incorrect because familiar topics may be easier for students but may not teach them anything new. Likewise, C is incorrect because exciting resources may provide students with too many ideas at once, making it hard for them to attend to the key ones, or may have students thinking about the resources themselves (for example, a pizza used to demonstrate fractions). B is most likely to reduce cognitive load so that students can learn.

Question A good explanation…

A. Is as detailed as possible.

B. Is as concise as possible.

C. Is as stimulating as possible (visuals, sound).

Answer & Explanation Making an explanation as detailed as possible or providing lots of stimuli places an additional burden on students' working memories, which makes it hard for them to attend to the key ideas. So, A and C are incorrect. B is correct: concision helps.

3. How can I help students to attend to learning?

Once we have decided what we are going to teach students in a lesson, we need to think about how to help them attend to – think about – the content of the lesson.

Research summary

Richard Mayer reviews a number of ways in which we can guide students' focus, removing distractions, focusing attention and helping them to generate connections. These include:

- Coherence – removing extraneous material
- Signalling – highlighting essential material
- Redundancy – narrating aloud, rather than asking students to read
- Spatial contiguity – applying helpful labels
- Segmenting – offering learner-paced segments
- Pre-training in key components
- Modality – offering spoken, not printed texts
- Multimedia – combining words and pictures, rather than just using words
- Personalisation – using a conversational style ('Your lungs', rather than 'the lungs')

Mayer, R. (2008). Applying the science of learning: Evidence-based principles for the design of multimedia instruction. American Psychologist, 63(8), pp.760-769.

Key study

Graham Nuthall tracked the understanding of individual students as a unit progressed, listening to every word they said and interviewing them about what they remembered and why they remembered it. He describes the different experiences of three students and whether they remembered that Antarctica is the driest continent:

Joy had four relevant experiences, wrote about them in her report and remembered them a year later.

Paul had four relevant experiences (such as hearing it mentioned by a teacher, or in a video), did not write about it in his report and more-or-less remembered a year later.

Teine had three relevant experiences, but in one of them, she was passing notes to a peer and discussing boys. She did not mention this in her report and did not remember it a year later.

Nuthall. G. (2005). The Cultural Myths and Realities of Classroom Teaching and Learning: A Personal Journey. Teachers College Record Volume, 107(5), pp. 895–934

Principle

We perceive thousands of stimuli at once, but we can only consciously attend to a handful. Only those we attend to can enter working memory, and, subsequently, enter long-term memory. We need to design resources, activities, instruction and environment so that attention is focused on the right things at the right times.

Analogy (and limitations)

Attention is a gatekeeper: if the gatekeeper does not attend to what is to be learned, that information or idea cannot pass through the gate into working memory.

Students' attention is a searchlight: what it lights up is what we can see clearly. So, we may wish to point the searchlight (directing students' attention through questions, for example, or removing distracting and redundant information), and then keep the searchlight in one place (by providing students with additional time to think about specific questions)

The Moonwalking Bear. Unfortunately, this video is now so well known it doesn't have the desired effect. Luckily the Monkey Business Illusion plays on this.

Applications

- Design questions that guide student attention to critical ideas.
- Cold Call: ask questions, then choose which students will answer, to ensure all students are thinking about the answer.
- Provide wait time: pause to allow students to think about the answer to questions before picking a student to answer.
- Cut redundant information from resources and design materials to focus student attention on the most important content. For example, don't speak over text.
- Use the modality effect: speaking over visuals can prove helpful.
- Limit distractions, whether from the external environment, peers, or us.
- Ask students to watch as we model; to help as we model, and then to do themselves.
- If students do not have all the information they need, help them to outsource thinking (temporarily) to carefully-selected resources, like notes.

Assessment

Question What is the best way to present information to students?

A. Speaking aloud over images.
B. Combining images and written text.
C. Talking to students with no additional resource.

Answer & Explanation Teachers may think that we can help students by not providing images, but relevant images with narration are better than no images. So C is incorrect and A is correct. Combining images and written text can prove distracting so B is incorrect.

Question Which of these is an effective way to keep students' attention?

A. Rapid questioning.
B. Exciting visuals.
C. Pausing before nominating a student to answer.

Answer & Explanation Teachers may think that they must maintain students' interest by increasing the pace of the lesson or increasing stimuli, when in fact, it is the focus of students' thinking that matters. So, A and B are incorrect and C is correct.

4. How can I help students to think hard about key ideas?

For information students are thinking about to begin to enter their long-term memory, we need to select activities which will help them to think hard about it.

Research summary

Willingham, D. (2008). What Will Improve a Student's Memory? American Educator. Winter.

Key study

Craik argues that the depth of processing learners do – the harder they have to think about an idea – the more they are likely to recall. He contrasts shallow, intermediate and deep processing:

- Shallow – How many vowels does a word contain?
- Intermediate – Does the word rhyme with tool?
- Deep – Is the object used to write?

Learners were more likely to recall objects which they were asked to process in deeper ways.

Craik, F. (2002). Levels of processing: past, present and future...? Memory. 10(516). pp.305-318.

Principle

Memory is the residue of thought: students transfer information into their long-term memories when they think hard about it, particularly if they think about its meaning.

Analogy (and limitations)

We rarely eat ingredients: we have to cook them to create a satisfying (and memorable) meal. In the same way, the information (ingredients) which enters working memory needs to be processed (cooked) in order to reach long-term memory.

Applications

- Select activities which help students to think hard about the key ideas; it may be helpful to ask all students to write their response to a key question before beginning a discussion, for example.
- Use tools such as mnemonics to help students to recall items where there is no obvious meaningful structure to place on them (like colours).
- Be wary of activities which encourage students to think about something other than its meaning: for example, asking students to build models of objects from history (e.g. castles, longships), will mean they spend most of their time thinking about craft skills, and very little thinking about the reasons for these design features.
- Stories seem to be particularly memorable for students (they require less hard thinking to enter long-term memory).

Assessment

Question An activity is most likely to help students learn if...

A. Students find it fun/interesting.
B. Students have to think about a large amount of content.
C. Students have to think about the meaning of content.

Answer & Explanation Teachers may think that a fun or interesting activity or a significant amount of content will help students, but the key idea is the thinking about meaning we are asking students to do. So, A and B are incorrect and C is correct.

Question Students learn best when they...

A. Experience a variety of types of activity.
B. Discuss their learning in groups or with a partner.
C. Are guided to think hard.

Answer & Explanation Teachers may think that variation or discussion is important in learning, but the key thing is what the activity or discussion is asking students to think hard about. So A and B are incorrect and C is correct.

5. How can I check student understanding?

We have planned activities which will help students learn something new; now we need to find a way to see whether they have understood what we hoped to teach them. We want to do this before we ask students to practise independently: practice makes permanent, not perfect. When and how can we check what students have understood and identify their misconceptions?

Research summary

Millar, R. (2016). Using assessment to drive the development of teaching-learning sequences. In J. Lavonen, K. Juuti, J. Lampiselkä, A. Uitto & K. Hahl (Eds.), Electronic Proceedings of the ESERA 2015 Conference. Science education research: Engaging learners for a sustainable future, Part 11 (co-ed. J. Dolin & P. Kind) (pp. 1631-1642). Helsinki, Finland: University of Helsinki.

Key studies

Student misconceptions are common, for example, a quarter of American 11-14 year olds believe that energy can be created and do not believe cells are made up of atoms, while a third believe that chemical changes are irreversible.

American Association for the Advancement of Science – Project 2061 Science Assessment Website

A study of science teachers' knowledge tested both their knowledge of the science they were teaching, and their knowledge of the misconceptions their students were most likely to hold. When teachers could predict students' misconceptions accurately, students learned more: teachers need to know how students may learn, not just the correct answer.

Sadler, P., Sonnert, G. (2016). Understanding Misconceptions: Teaching and Learning in Middle School Physical Science. American Educator. Spring.

Principle

Students may hold existing misconceptions or form new ones as they learn: if they maintain these misconceptions, this is what they are likely to recall. We need to identify what students are thinking and have understood during the lesson, without waiting for misconceptions to emerge. (It may be worth teacher-educators referring to Principle 7 when introducing this principle, to highlight that students' current understanding reflects temporary performance, not long-term learning).

Analogy (and limitations)

The first time we learn something is like scratching a shape in the sand. The tide will come in and (mostly) remove it – only a faint shape will remain. If we got this shape wrong the first time around, going over it will result in reinforcing the wrong impression. Therefore, it is vital to ensure that the initial impression students make of information is correct.

A captain is able to steer their ship to its destination by having planned a route, taking constant readings of weather and currents during the journey and making careful adjustments in response to those readings. In the same way, teachers steer their students to a learning destination by planning a carefully chosen route ahead of time, taking readings along the way and changing course as and when conditions dictate.

Applications

- Asking students for a subjective assessment ("Does everyone understand?") often leads to misleading data.
- Low-stakes tests help students to learn and provide students and teachers with a check on students' understanding.
- Exit tickets and weekly quizzes help show what students have understood and the misconceptions they may hold. Hinge questions do the same during lessons.

Assessment

Question The most important reason to check understanding during a lesson is to...

A. See whether students will remember what we have taught them.
B. Demonstrate that students have made progress.
C. Identify misconceptions students hold.
D. Allow the class to move on.

Answer & Explanation Teachers may believe A – that an immediate check for understanding means students will recall key ideas indefinitely; that is, they may believe that current performance guarantees learning – but this is incorrect. They may believe the purpose of such checks is to demonstrate students have made progress (B) or allow the class to move on (D); but both of these are incorrect: the most important reason to check student understanding is C, as it allows teachers to adapt the lesson to students' needs.

Question Checking for understanding could be omitted when:

A. We have provided a sufficiently clear explanation.
B. Students confirm they have understood.
C. The next activity will show whether students have understood.

Answer & Explanation Teachers may believe that some explanations are so clear they need not check for understanding (A) or that student self-report is sufficiently reliable to confirm understanding (B). C is the only situation in which we can reasonably proceed without checking for understanding – although this may also prove problematic if students do not understand what we want them to do.

Question Checking for understanding can be problematic if:

A. Students are slow to answer correctly.
B. It embarrasses students.
C. Students make mistakes.
D. We are unsure how to respond to student misconceptions.

Answer & Explanation A, B and C are incorrect. Teachers may believe that students should respond quickly or that they should avoid identifying gaps in student understanding to protect students' confidence; they may believe that mistakes are a bad thing, rather than providing useful information. D is correct: teachers who are unsure how to respond will struggle to proceed with the lesson.

Question We are most assured that students currently hold no major misconceptions if:

A. Students confirm they have understood the key ideas.
B. Targeted students answer oral questions well.
C. Students respond to an exit ticket or hinge question.

Answer & Explanation Teachers may be satisfied with student self-report or believe that oral questions to some students provide sufficient information about the whole class's understanding. But A is incorrect because student self-report is an unreliable measure and B is incorrect because the response of some students may not represent the understanding of the whole class. C is correct.

6. How can I help students to gain fluency?

Having introduced students to knowledge, we want to help them consolidate learning and practise skills: we want students to be able respond fluently.

Research summary

Willingham, D. (2004). Practice Makes Perfect—but Only If You Practice Beyond the Point of Perfection. American Educator. Spring.

Key study

Rohrer and Taylor taught students how to find the volume of obscure geometrical solids. They then either conducted:

- Spaced practice (four practice problems split across two sessions), or
- Massed practice (two or four practice problems in one session)

Students who conducted spaced practice scored far better on a subsequent test. They then asked some students to conduct either:

- Mixed practice (32 problems randomly ordered), or
- Blocked practice (practising similar problems together)

Students who conducted mixed practice scored worse initially but far better than students who conducted blocked practice in a subsequent test.

Rohrer, D., Taylor, K., (2007) The shuffling of mathematics problems improves learning. Instructional Science 35: pp.481–498.

Principle

Learning is a persistent change in long-term memory. Ensuring that learning sticks persistently in the long-term memory requires students to practise using and retrieving this information. Practice increases recall, particularly if it is spaced (there is a delay between practice episodes) and mixed (students practise different tasks, rather than one task at a time). Practice can be beneficial even when students already respond correctly, as 'overlearning' increases the likelihood of subsequent recall of knowledge and their fluency with tasks.

Analogy (and limitations)

Practice makes us familiar with the basics and allows us to adapt them. 'The Knowledge' tests cab drivers' knowledge of London streets. They must learn 320 basic routes, all the 25,000 streets that are scattered within the basic routes and approximately 20,000 landmarks and places of public interest that are located within a six-mile radius of Charing Cross. For this, they must gain fluency and accuracy in their journeys so that they can then begin to alter their routes if there is a collision or road closure.

Applications

- We can provide students with practice.
- Students should begin with guided practice, where the teacher ensures that students are practising in the correct way.
- Guided practice should be followed by independent practice, where students work alone on new material.
- We can make practice more effective if it is:
    - Spaced – Students receive multiple opportunities to practise
    - Mixed – Students are not simply repetitively practising the same skill or action but have to think about it each time.

Assessment

Question Students benefit from practice if…

A. They are not yet good at what they are practising.
B. They are already good at what they are practising.
C. Both of the above.

Answer & Explanation C is correct. Students need to practise both what they are not yet good at and what they are already good at.

Question Practice is more likely to be helpful if…

A. It allows students to keep practising the same thing until they are good at it.
B. Mixes problems up, so students practise many different things in a short period of time.

Answer & Explanation A is incorrect. B is correct because it makes use of the learning benefits of mixed practice (NB there are limits to this research outside maths).

Question It is more effective to give students...

A. An hour of practice in a skill at once.
B. Half an hour of practice this week, and half an hour next week.

Answer & Explanation A is incorrect. B is correct because it makes use of the learning benefits of spaced practice.

7. How can I ensure that students maintain this learning?

Introducing students to an idea once is very unlikely to be enough for them to recall it after a term, a year, or beyond. We need to return to ideas many times for students to learn them.

Research summary

Brame, C. and Biel, R. (2015). Test-enhanced learning: The potential for testing to promote greater learning in undergraduate science courses. CBE—Life Sciences Education 14, pp.1-12.

Key study

There is a critical distinction between:

- Learning, a permanent change in behaviour or knowledge, and;
- Performance – a temporary fluctuation in behaviour or knowledge which can be observed and measured during and immediately after acquisition performance.

Approaches which increase learning in the long-term can have no effect on performance, or can even decrease it. We can promote learning through desirable difficulties, like distributing practice – separating practice sessions in time – as well as varying practice. Retrieval practice – revisiting key ideas – can be very helpful. Performance tests retrieval strength – how easy it is to recall something; desirable difficulties depress performance but build storage strength – increasing the likelihood of long-term recall.

Soderstrom, N., Bjork, R. (2015) Learning Versus Performance: An Integrative Review. Perspectives on Psychological Science, 10(2) pp.176–199.

Principle

We need to ensure students learn – that there is a persistent change in what they know. To do this we need to:

- Differentiate between students' current performance and lasting learning;
- Seek to boost the storage strength of what students have learned – how likely it is to be recalled in future;
- Keep revisiting key ideas.

Analogy (and limitations)

The first time we learn something is like scratching a shape in the sand. The tide will come in and (mostly) remove it – only a faint shape will remain. The more times we go over this shape, the more resilient it will become to the blurring effects of the tide.

We may not think about our childhood route to school for months on end, but if we were to return there, we would recall it (because the storage strength is high); if we retraced our footsteps, we would recall it much better the next day.

Someone may be able to tell us what they had for breakfast this morning; this does not mean they will be able to recall what they had for breakfast on a given day in a year's time.

Applications

- Practice is essential for learning new facts, but some types of practice work better than others:
  - Retrieval of knowledge from long-term memory to working memory strengthens storage. Every time students retrieve knowledge, doing this in the future becomes easier. Low-stakes quizzing can support this.
  - Spaced practice helps students remember content in the long term: rather than asking students to practice the same content in a continuous chunk, we should leave gaps of increasing length before returning to content.
  - Interleaved practice is more effective than massed practice: we should mix up the content that we are asking students to retrieve rather than asking them to retrieve the same content all at once.
- Plan to revisit material introduced in past lessons.

Assessment

Question We can say that students have learned something from a lesson if…

A. They complete the exit ticket correctly.
B. They remember the key idea the following lesson.
C. They remember it a year later.

Answer & Explanation A and B are incorrect because they are indicative of gains in performance, rather than learning. C is correct.

Question We can effectively quiz for retention…

A. Immediately after the lesson and then every lesson after this.
B. Immediately after the lesson and then with increasingly long pauses before re-quizzing.
C. After an initial long pause.

Answer & Explanation A is incorrect because quizzing immediately after the lesson leads to gains in performance. C is incorrect because students are likely to forget the majority of what they initially knew. B is correct.

8. How can I help students to connect ideas?

We've supported students to recall ideas and to respond fluently to questions, but we want to go beyond this, and see students connect what they have learned to other ideas, allowing them to think flexibly and creatively.

Research summary

[Pan, S., Agarwal, P. (2018). Retrieval practice and transfer of learning: fostering students' application of knowledge. Retrieval Practice.]

Key study

For simple tasks, we can encourage transfer by varying practice, limiting guidance and reducing feedback. For complex tasks this is more complicated: adding this germane cognitive load makes it even harder to master already complex tasks. However, we cannot simply cut germane cognitive load, as this means students will not be able to transfer learning. Instead, we can limit how complex the tasks are, either introducing parts of a complex task at a time, or starting with the whole task, but focusing on certain aspects at a time. We can therefore continue to vary practice, limit guidance and feedback, and so ease transfer.

[van Merriënboer, J., Kester, L. and Paas, F. (2006). Teaching complex rather than simple tasks: balancing intrinsic and germane load to enhance transfer of learning. Applied Cognitive Psychology, 20(3), pp.343-352.]

Principle

We can help students to apply their knowledge by encouraging them to make links between ideas and to apply them in a variety of situations. We can also help them by showing them how knowledge is organised; highlighting the underlying principles and links between key ideas.

Analogy (and limitations)

If working memory is like gathering shopping in our hands, we can help students by providing them shopping bags into which to put objects – ordered according to what should go together. They can then carry more shopping. When they get the shopping home and organise it in cupboards, this becomes even more helpful.

When students initially acquire some new knowledge, they can see the trees but not the forest. They need to zoom-out to see the relationship between the parts. Students need to be guided to think about these relationships (the whole) as well as the facts themselves (the parts). (Limitation: students need to have a good understanding of the parts if they are to identify meaningful relationships between them; teachers may be tempted to jump to making links too early).

Applications

- Help students make meaningful links between what they know:
    - First ensure that students have a good grasp of the building blocks, following the principles above.
    - Help students to see the whole picture by highlighting the links between these building blocks.
    - Ensure students have adequate thinking time to identify how new learning can be connected to what they already know.
- We understand new ideas via examples but it's often hard to see the underlying concepts in different examples. New material is best presented using lots of concrete examples.
    - For multi-step problems, encourage students to identify and label sub-steps required for the solution. Students are more likely to recognise underlying structure of problem and be able to see this in similar problems.
    - Move from concrete to more abstract representations (for example, from images to formulae) to help students see the underlying structure.
    - Provide students with multiple examples that are slightly different to each other: ask students to compare the examples and identify differences.
- As students improve their mastery of content, remove scaffolds and supports to increase their independence.
    - Scaffolds and supports should be seen only as temporary fixes – we think with knowledge, not just about it.
    - Reduce the guidance and feedback we offer students as they progress.

Assessment

Question We can help students use their knowledge flexibly through…

A. Training in thinking skills, such as problem solving and critical thinking.
B. Giving them complex problems and encouraging them to solve them as an expert would.
C. Reminding students to use knowledge in new contexts.

Answer & Explanation A is incorrect because thinking skills training has very limited impact because thinking hard and solving problems relies on knowledge of the domain. B is incorrect because students are unable to solve complex problems as experts without the knowledge base an expert has. C is correct.

Question Given a problem with a similar structure but different superficial features to a problem they have previously solved, most students are likely to…

A. See the link
B. Not see the link

Answer & Explanation A is incorrect. Numeracy studies have found that students (and adults) are unlikely to see the link between problems unless they are experts in their field. B is correct.

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