Penguins, polar bears and icebergs: Theory and strategies for teaching mathematics and science in a second language

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Abstract

Priming context and structure is a well known but under utilised strategy to improve memory and learning. Neural network modelling of the brain and mind suggests a complication of the learning curve model involving repetition and links at different levels of understanding. The second language setting presents additional cognitive obstacles requiring distinctly refined strategies if students are expected to succeed. We sketch some of the pertinent theory and suggest some practical strategies related to teaching subject context in a second language. We also make some informed suggestions towards the effective use of technology in the mathematics, computing and science classroom.

Introduction: Memory and perception

From early work by Vygotsky and Samuel Renshaw to Kurt Fisher's *Mind, Brain and Education* programme at Harvard University (Fischer, Bernstein and Immordino-Yang, 2007; Fischer and Rose, 1999), the progression of our understanding of how memory and learning occurs has greatly increased in the last hundred years or so. Yet, there has been little progress on the teaching front. A recent *Time Magazine* article puts it clearly, our [US public] schools tend to feel like throwbacks (Wallis and Steptoe, 2006). Is your classroom any different from fifty or even one hundred years ago? Is the highest level of technology change a dry whiteboard marker? Given this reality, what is the state of our understanding of how memory and perception related to learners in these classrooms? New research on memory and the way the brain works, along with the tools of neural network modelling, might mean the end to some of our most cherished ideas. The up side is that some of the teacher's intuitive perceptions turn out to be correct. Let us start with Gestalt theory as a descriptive paradigm.

> To apply the category of cause and effect means to find out which parts of nature stand in this relation. Similarly, to apply the Gestalt category means to find out which parts of nature belong as parts to functional wholes,

> to discover their position in these wholes, their degree of relative independence, and the articulation of larger wholes into sub-wholes (Koffka, 1935).

As Koffka describes it, the idea of the Gestalt category, or what is now generally referred to as Gestalt psychology, proposes we think holistically and that the ability to perceive and remember relies on the form of the information more than the type of data experienced. In addition, Gestalt and the neural network model suggest that memory self-organises relating to form not data.

Figure 1: Young woman and old woman.

The famous visual illusion pictured in Figure 1 shows us how the mind tends to organise data (Wright, 1992; Fisher, 1968). Looking closely, two possible perceptions are possible; a young woman and an old woman. The perception depends on what part of the image is the start of your apprehension or focus. It is also apparent that the data itself can have an impact on the apprehension of data. Consider the seven character sets listed in Figure 2. Using the Renshaw tachistoscope approach, each of these sets is flashed on a screen for half a second and viewers are asked to attempt to recall as many characters as possible.

Predictably, in a crowd of teachers, Set F is best recalled. It provokes the highest level of response in terms of recognition. During our presentations in the Middle East, we notice that Set E also returns a high level of response with native Arabic speakers, which is understandable since the characters are part of the Arabic language. Set G is the hardest for any one person to keep in memory, since it draws on characters from three different language alphabets.

Set A	24681012
Set B	12345678
Set C	39741050
Set D	210 YFN
Set E	جُحَا وَحِمَارُهُ
Set F	PAY RAISE
Set G	בFθא□5♂

Figure 2: Renshaw tachistoscope of characters sets.

Recognition of characters conforming to memorable words or phrases gives an explanation of why acronyms work so well. We can recall a simple list of letters, but we remember better if the list has some addition meaning, or is at least pronounceable as one word. ETA, estimated time of arrival or P2P, peer-to-peer are examples of good acronyms. SOH CAO TOA and BEMDAS are examples in teaching order of operations and relationships in trigonometry:

B – brackets
E – exponents
M – multiplication
D – division
A – addition
S – subtraction
SOH – 'Sine over hypotenuse'

Further analysis might be extended by asking for written responses. Of interest would be to further classify the most easily remembered perception, Set F: PAY RAISE, between UK-schooled and American-schooled viewers. The regional UK alternative of the phrase would be pay 'rise'. Thus, for a UK-schooled person, it might be expected that the spelling of the word 'raise' is given as 'rise'. In other words, regional phraseology might overrule the actual phrases flashed. This is supported by experiments where subjects record seeing not what is shown, but what they wanted to see. People do indeed see what they expect to see. And, the complexity suggested by early Gestalt theory was only the beginning.

We now know that the very complex neural network modelling of the brain is the most promising theory going. This theory suggests that neurone cells are organised into very large and complicated intercommunications networks (Fischer and Rose, 1999). These networks are connected hierarchically, but are also cross-connected at various levels. This makes memory mapping a much harder task and it also makes it less obvious how and why learning takes place. Thus, it is understandable if some basic ideas of learning are challenged by new evidence.

Miller (1956) demonstrated that only six to seven characters can be identified out of a group that is flashed on a screen. In the 1940s, Renshaw was able to increase the detail of memory of images by directed practice. This did result in a higher number of characteristics remembered than Miller could reproduce in 1956, but Renshaw's training was aimed only at visualisation and identification of images of aircraft. Miller and others failed to show that visual identification skills transferred to other areas. Indeed, little, if any, evidence exists that shows that 'Renshawing', as the skill is referred to, can be transferred at all. Miller and Huitt confirm that situation memory links seem to be fixed around the six or seven mark (Miller 1956; Huitt, 2003).

Oviously, this limitation presents a major obstacle to teaching science or mathematics in the second language setting. The subject of mathematics or science introduces memory links. The second language requires an additional second link. Together they greatly reduce the available memory for thinking.

A cat named George

Many years ago Nancy had a very bad cat named George. He was a real pleasure to have around but had a nasty habit of marking his territory despite her continuous pleas with him to change his behaviour. Eventually a friend who lived outside of town agreed to give George a home in his barn. It was toasty warm in the winter, there were plenty of cool places to hang out in the summer and he could have fresh farm milk every morning. This sounded like an ideal place for George to spend the remainder of his years so off he went. Approximately six weeks later George returned to Nancy's, more than four kilometres in distance. There stood George. He looked the same as the day he was dropped off outside of town. It was amazing what a cat was capable of, and it begs the questions, 'What would a human be capable of doing?' George demonstrates a level or type of intelligence not found in humans. In a similar situation, the average human would be hard pressed to achieve return after a major geographic displacement.

In a similar way, our students differ from teachers in that they have native intelligence in areas we lack, and lacking in areas we are attempting to teach them. We can best approach this by addressing various learning styles that meet the needs of the students. And remember, just because it worked for us does not mean it will work for our students.

For example, when teaching the concept 3 squared times 3 cubed ($3^2 \times 3^3$), we show the students 3 times (2 + 3) is equal to 3 to the power of five. When we have a problem like 3 squared cubed, we show that it is like 3 squared times 3 squared times 3 squared, or 3 to the power of six. It is assumed that once shown we could move onto the next concept. However, we get students who fail to remember when faced with problems with combined items. They just do not get it. We try to come up with ways to help. Nancy has reasoned, since the 3 raised to the power was going up, she would teach the phrase, 'To the sky multiply'. Years later she had a student come up to her repeat over and over, 'To the sky multiply,' with thanks because the phrase made a big difference in her success. The student still remembered how to work exponents years later. Obviously this student needed something to assist the memory of this concept.

In addition to links there is also the issue of the prime learning stage as outlined by Chomsky (1988). Chomsky states that a pigeon learns to fly at approximately two weeks because it has to learn to fly at this time. If you were to keep the pigeon in a box so it can not move its wings until this age and then you let it out of the box, it will fly just as well as any pigeon that has been sitting on the nest all that time. But if you keep it in that box another week or two and then you let it out of the box, it will never learn to fly. It is very probable that language works in the same way.

Most biological capacities have a time at which they have to operate and they will not operate before or after that time. Chomsky (1988) believes that learning a word for a child is simple because human nature gives us examples that enable us to interpret experiences available to us before we necessarily have the experience. We can learn the label that goes with the pre-existing concept. Chomsky also suspects that something happens to the brain about the time of puberty which triggers this ability to move up a level. This is the prime stage of learning at this logical-deductive level. Denied the actual examples and experiences, students who come to us in university 'untaught' have missed the prime time to learn. This does not mean that learning is impossible, since humans are much more flexible learners than pigeons. But it does mean that later life learning needs more work since given the lost opportunity. Further learning must come at the cost of overcoming obstacles including undoing poor or incomplete learning strategies. A major part of encouraging learning at this stage is reintroducing an environment that is more like the prime stage using a diverse medium of delivery, taking advantage of as many experiences as possible.

Icebergs and brains: Levels of understanding

In order to tackle this seemingly massive challenge we always need to keep in mind that students in the United Arab Emirates are second language (L2) students. This brings a whole different set of issues and possible experiences into the picture and briefly we need to look at learning in the L2 environment.

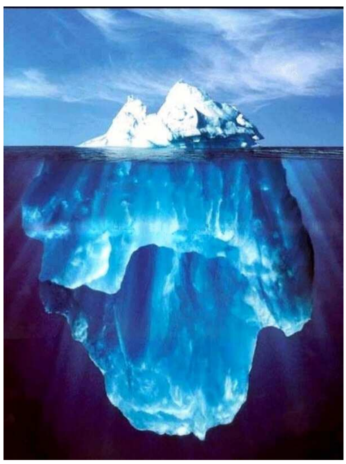

Figure 3: Iceberg off the coast of Newfoundland.

Learning memory can be modelled by the idea of an iceberg, as pictured in Figure 3. Think of the portion of the iceberg below the surface of the water as long term memory. Naturally it contains more information and so it is much larger than the part of the iceberg which is above the water. The part above the water is the working memory, similar to a chalkboard. When our students are engaged in a learning activity the situation is almost like working on a chalkboard, in that if we do not permanently place the information in our long term memory, or below the surface of the water, it can easily be erased or be forgotten. And, just like an iceberg, the import bits are under the water.

Recall that the magic number seven; the number of simultaneous items that can be productively work on in our working memory. If our chalkboard upper memory gets too full, some information will be erased or lost, due to the overflow of information dealt with at one time. Our L2 students are not only learning the content but they have language issues to deal with as well. Jim Cummins' hypothesis on interdependence of languages (1981) *Iceberg theory* is most helpful when considering how an L2 student learns.

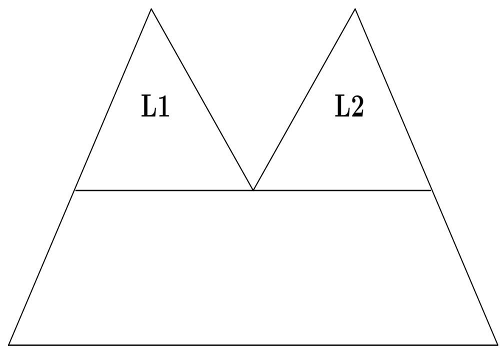

Figure 4: Three-part iceberg (after Cummins, 1981).

Again think of the iceberg but this time think of L2 students. On the surface, the first and second languages appear to be functioning in isolation, but under the surface there are intellectual processes that are common to both languages. When a student is attempting to solve a mathematics problem they are using intellectual processes that are common to both languages. We want the student to be able to transfer concepts from L1 to L2 and we want the student to be able to express knowledge in short term memory procedurally in L2. This takes time and lots of practice.

Cummins' hypothesis is that first language learning proficiencies can be transferred to the second language learning context. The unique aspect of the use of Cummins theory is that this hypothesis could also work in reverse. That is to say, at the same time that learners are learning a second language, they are also developing capacities which could be used in the first language learning setting (Netten and Germain, 2002a, 2002b).

For example, a student is given an order of operations problem like the following:

$$6 + (3 \times 7) - 5 = ?$$

As the student begins the process, they are using their working memory or the part of the iceberg above the water. They learn the principle of solving what is in brackets first, followed by the addition and subtraction as it occurs from left to right. But when the student solves the first step, the multiplication of three times seven, the student will switch to their long term memory and come up with the answer. This will free up space in their working memory, making this an automatic process. One of our goals is to increase the number of processes that occur. The more often this happens, the more often information in the working memory is minimised. Furthermore, since the mind has the ability to carry out rich complex processes without deliberations, we want to channel as much as possible into long term memory.

Suppose Mohammed, a native Arabic speaker, suffers from a severe head injury and loses his ability to speak and understand. Has he lost his knowledge of Arabic? Not necessarily. As he recovers, his ability to speak and understand Arabic improves and not an ability to speak and understand English. He does so without instruction in Arabic. Had his native language been English, he would have the potential to recover the ability to speak and understand English, not Arabic, also without instruction.

Brain injury cases demonstrate that the human cognitive system have complex connections and levels between long and short term memory. Possession of a certain type of knowledge cannot be identified with the ability to speak and understand. It is not a habit or a skill but a permanent system that constitutes knowing how to speak and understand Arabic. This type of memory and skill takes more time to develop and will require extensive practice.

Another of our goals as educators is to channel as much information as possible into long term memory so our students can eventually reach this level of skill. According to Chamot and O'Malley (1994) the challenge is to prepare the L2 students to express knowledge in working memory, acquired in either L1 or L2, procedurally through L2. A crucial factor in effecting this transition is the implementation of learning strategy instruction. In other words, in learning a complex cognitive skill there will be advantages to using modelled performance of the task as well as strategy training.

O'Malley and Chamot (1990) suggest that learning strategies or procedural knowledge in the learner's L1 could be transferred to the new conditions in the L2. They go on to say this is extremely difficult to do because of the added load to short-term memory processing requirements which are already burdened by trying to decode the new language. Thus, repetition and practice of the learning strategies can only be beneficial as they will enable them eventually to become more automatic, freeing up the short term memory to focus on other information.

Perhaps we can devise a way to get students to learn so they can use their long term memory – the part under the water – more, which will free up more of the working memory. We want to work on strategies to help get more of the content we are teaching into long term memory.

Strategies

What do we mean by strategies? The word 'strategy' comes from the Greek *strategos* that means 'deception' or 'to trick'(Town, 2006). It was first used in cognitive psychology in 1956 and, in applied linguistics, the strategy research dates back to 1966. There is a great deal of research that has been conducted on theoretical framework for language learning and this has led to a whole range of strategies used in vocabulary learning tasks, reading comprehension and writing.

There is no agreement on exactly what learning strategies are or how many of them there are and what they consist of. In essence, strategies are what learners do to regulate their learning. Gagne (1985) describes it as skills by means of which learners regulate their own internal processes of attending, learning, remembering and thinking. O'Malley and Chamot (1990) say that learning strategies are 'special ways of processing information that enhance comprehension, learning or retention of the information'. In addition, O'Malley and Chamot advocate that certain strategies should be taught to all students and that different learners prefer to process information at different levels. We have found that learning strategies interact with the learners' existing communicative competence in order to enhance learning.

Oxford (1990) stresses the importance of cues for improving all four types of learning skills: reading, writing, listening and speaking. She goes on to suggest that building guessing skills step-by-step in students is important and that working on memory practice and asking students to share ideas for how they remember new vocabulary words is necessary. In addition, she recommends that teachers act as role models by thinking out loud and demonstrating to their students their own learning strategies. The teacher as a mediator helps students organise information and mental processes, thus helping the students to become autonomous learners.

Furthermore, students who do not seem to realise that a learning task or activity is not progressing well can be taught to monitor or check their comprehension and progress so they can identify where they are having difficulties and select problem-solving strategies to address the difficulties (Chamot and Kupper, 1989).

Learning strategies are difficult to observe and only by asking students can we discover which strategies are being used. It may be difficult for the student to articulate the strategy or to correctly identify exactly what they did. These strategies however need to be facilitated through teacher demonstration and modelling. It is important to provide multiple practice opportunities with the strategies so the students can use them autonomously.

Strategies should be based on the students' attitudes, beliefs, and stated needs. They should be chosen so they mesh with and support each other so that they fit the requirements of the language task, the learners' goals, and their style of learning. This approach should be integrated into regular L2 activities over a long period of time rather than taught as a separate, short intervention. Educators in content classes cannot simply ignore content for strategies and so a mixed approach must be used here.

Learning strategies should also not be permanently tied to the content or class but should aim towards transferable tasks beyond a given content or class. Oxford (1989) says that consideration needs to be given to different genders, cultural backgrounds, motivation, learning styles, and attitudes and beliefs. Thus, approaches should be individualised and allow students to develop mechanisms to evaluate their own progress and the value of the strategies in multiple tasks.

Krashen (1982) contends the focal point for an effective second language programme is the creation of situations in which students have opportunities for interaction. He went on to stress the importance of 'comprehensive input' in order for a person to acquire a second language. Swain (1985) affirmed the necessity for output. We need to work to combine these concepts in input and output to increase communicative competence. Ideally that would include work on facilitating interaction between students and the teacher thereby creating an environment rich in spontaneous and meaningful language. This could be done with the use of cooperative learning activities. Krashen

(1982) argues that cooperative learning is firmly rooted in language acquisition theory in that it focuses both on the provision of comprehensible input and the opportunity for producing output. Well-designed cooperative learning tasks involve the negotiation of meaning within a communicative context, an essential process for effective second language learning. Ideally in a cooperative learning environment, the environment should support student risk-taking and encourage them to assist one another.

Structured cooperative learning activities will provide the basic foundation for a well-managed classroom where students understand what is expected of them, what their roles are, and what the rules are, thereby creating a language learning environment ripe for success. Cooperative learning activities can also be an effective means of integrating students with special needs. Chamot (2004) says that ideally teachers should integrate strategy instruction into their course work and it should be included in all classes. She says this would make it more likely that students would transfer strategies learnt in one class to another class. Oxford (1990) says it is better if students can develop a wide repertoire of learning strategies. Therefore, learning multiple strategies would appear to be beneficial. Teachers provide increased amounts of naturalistic communication in their classroom, and the environment will be more conducive to a good language learning experience.

Learning strategies should be integrated into the learners' L2 activities over a period of time, not taught as a separate intervention. They should be transferable to future language tasks and work on memory practice, and the teachers should act as a role model. Learning strategy instruction can help learners to become better learners, become more independent and confident learners, and be more motivated as they begin to understand the relationship between the use of strategies and success in learning languages (Chamot and Kupper, 1989; Chamot and O'Malley, 1994). Learners without metacognitive approaches are essentially learners without direction or opportunity to review their progress, accomplishment and future directions (O'Malley, Chamot, Stewner-Mazanares, Russo, and Kupper 1985).

Imagine the increased difficulty for L2 students. The importance of tunnelling as much information as possible into long term memory and the necessity of comprehensible input and output needs a plan to improve the method of teaching strategies while also teaching content. This plan incorporates preparation, presentation, practice, evaluation and expansion. The preparation stage helps students identify the strategies they are already using by setting specific goals, and plan time to accomplish the tasks within the given time. Presentation models the learning strategy, talk about the usefulness, applications of the strategy through examples and how to look up a vocabulary word they encounter in a text. Taught that no single vocabulary strategy would work in every case, look for contextual cues for guessing the meaning of unknown words. Practice with an authentic learning task, recognise strategies available to them, how to recognise if a strategy is not working and how to move to another. Evaluation is through an evaluation of the student's own success in using learning strategies, using self-questioning, discussions about strategies' practice, checklists, open-ended questionnaires where students express their opinions about the usefulness of employing strategies. Finally, expansion uses strategies towards new contexts. Strategies that the teacher finds most effective and a result of individual combinations and interpretations that work in a particular setting, group or classroom. Part of the structure is to reduce the time spent on checking strategies as the use of strategies will eventually change from factual knowledge to procedural and as a result become more automatic. The strategies need to be continuously reinforced by the teacher.

Any organism needs a rich and stimulating environment in order for its natural capacities to emerge. Is this how you would describe your classroom? Teachers need to awaken the natural curiosity of the students and stimulate their interest in exploring on their own. What students learn passively is quickly forgotten, but what students discover for themselves through natural curiosity and creative impulses will be remembered and serves as the study basis for further exploration, inquiry and perhaps even significant intellectual contributions (Chomsky, 1988).

Let us imagine a physicist who is trying to figure out what is happening inside the sun. The easy way to answer this question would be to put a laboratory inside the sun and perform experiments. Since this is not possible, one must look at the light that reaches us from the sun and try to imagine what is happening to produce that kind of light. This is very much like trying to figure out what is going on in the physical mechanisms of the brain. We can see the results outside, but we are only conjecturing about what goes on inside. Use common sense and use your experience and do not listen too much to the scientists unless you find what they say is really of practical value and of assistance in understanding the problems you face (Chomsky, 1988).

Repetition priming and the learning curve

A common lamentation among mathematics and science teachers is the seemingly endless need to repeat basic information. They just do not get it sometimes. Once a new concept is introduced, well explained, demonstrated and understood by the learner, the expectation is that the learner has 'got it'. But just a little while later, the understanding falls apart. The understanding is once again built up and later it again falls apart; if the situation of the problem changes, the understanding fails once again. It seems almost that each new situation results in a failure of the understanding. Teachers know that the context must be changed in order to increase the chance of making a connection within the scope of repetition. Certainly flowing between two languages makes the context changes more difficult for the learner.

What makes this particularly vexing is the teacher expectation that students should follow some kind of learning curve. A sample curve is given in Figure 5.

Does the learning curve given in Figure 5 match your experience with teaching and learning? The problem with this model of learning is that it is behaviourally-based on learning physical tasks and was not developed for higher levels of learning. The model was first applied to a study of aeronautical assembly line workers in 1936 by T. Wright (Wright, 1936). It is practically at the level of an urban myth that students should demonstrate such a common learning model. Indeed, it is so common that researchers regularly supersede within the curve more complicated approaches. Wightman and Lintern (1985), for example, suggest a format that systematically repeats earlier parts within a chain of learning on a learning curve for complicated tasks. The bottom line is that repetition is necessary to learning and that repetition still does not always improve learning.

Alternatively, Fischer and Rose point out that higher learning is best modelled by

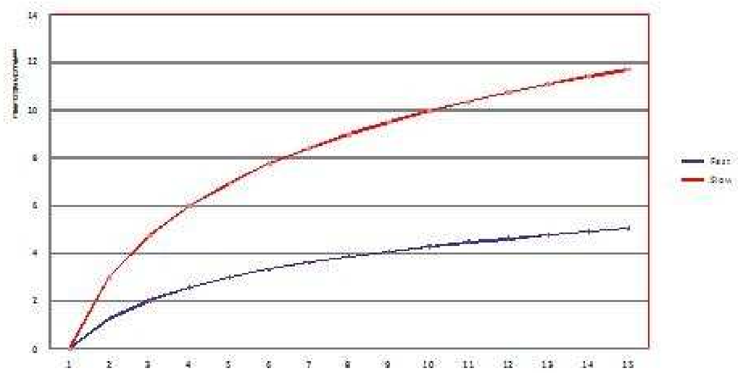

Figure 5: Sample (hypothetical) learning curve.

more of a cyclic process than a exponential–logarithmic one (Fischer and Rose, 1999). You learn a new understanding and it falls apart. Repetition is necessary and seems not to improve learning. This is typical of learning models. Each time there is a change in the situation, you start over. Thus, learners can seem to have grasped a concept at one point, but very quickly lose the ability. Fischer and Rose state that since this is the learning model expected, one should therefore design learning according to this model and not the traditional learning curve intelligently and one should use technology to increase access and offer repetition towards the goal. Thus, the learning curve in Figure 6 is a better match with our experiences in the classroom.

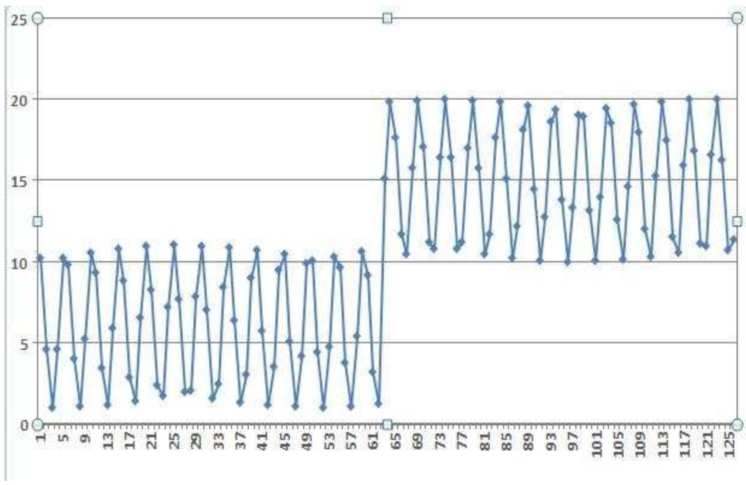

Figure 6: A learning curve that demonstrates a realistic cycle of higher learning.

Final note: Strategies and technology

Higher-level learning is an iterative and interactive process that builds up complexity, something process educators think of strongly (process education). Notice that it is repetition and priming that eventually cause a shift in learning from the lower level to the higher level. The keys in priming the shift are through understanding the student and the context of the material and making use of key items to make the material real, interesting, loud and colourful. Organise representation, perhaps using technology, to support and force pattern and organisation. Further, support should be given that keeps the learner at the optimal part of the learning curve. This means one should try to keep the learner at the top of the cycle. Knowing what characteristics are needed at the bottom of the next level helps the teacher to choose items that will prime the learner to jump levels. Finally, it seems reasonable to abandon the idea that this process is a smooth process built up of increasing concepts. The actual learning process is discontinuous and rough. Expect and understand that the learner will sometimes seem to have lost all advancement. Additional key characteristics of priming learning towards the next level include giving prototypic answers, structures, and learning strategies. Being repetitive and making good use of technology towards supporting both the current level and helping prime the next level is also recommended. Repeat in multiple contexts. For example, solve problems alternatively with a calculator, without a calculator, formula, no formula, both in and out of the multiple language setting. Practice and remind students thirty minutes before a test or examination of the material at hand. Finally, technology poses a number of possibilities. The polar bear and penguins in the title of this paper refer to a motivational video often used in our classrooms. Penguins dancing excitedly as students at the end of the week; the polar bears dragging themselves around like Monday (Sunday) morning office workers.

Figure 7: Image clips from Monday versus Friday video (source anonymous).

We have presented an analysis in miniature of the progression of how memory and learning supports recent trends using neural network modelling. The second language setting in mathematics and science is demonstrably more difficult for students and this fits the paradigm of memory and learning theory. The obstacles presented clearly suggest that a reduction and/or consideration of the number of situational links are necessary to improve learning for L2 learners. We have also presented some strategies that may prove useful in the practical situation of our classrooms that help make the connection between types and levels in the network of memory. An alternative learning curve supports what we see in the classroom and suggests that repetition priming should be one of the tools in our classrooms, in addition to a plan of preparation, presentation, practice, evaluation and expansion. Effective use of technology in the mathematics, computing and science classroom necessarily takes advantage of the characteristics of repetition priming, but also presents possibilities in enriching and linking context. Further research into different methods and timing of repetition priming and the appropriate timings of technology would help promote informed decisions towards improving learning and memory.

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