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Spaced Learning applied to teaching biology

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Abstract.

Spaced learning is a novel teaching strategy which has used results from neuroscience research as the basis for its design. Neuroscience research supports the need for a temporal pattern of repeated stimulation of neural pathways in order to produce long-term memory. More specifically, a neural pathway needs repeated stimulation with a separation of at least ten minutes between stimulatory inputs in order for optimal memory retention to be attained. The ten minute gaps between stimulation represent the time needed to allow molecular processes within the neurons to take place, in order to strengthen the synaptic connections involved in creating a long-term memory.

Spaced learning is a teaching method developed on the bases of these neuroscience observations. It is designed to enhance long-term memory of the subject matter taught. The technique uses short (usually eight to twenty minutes) periods of intensive learning separated by ten minute periods of “distractor activities”. These may take the form of physical activities such as ball sports or clay modelling and are aimed to take the mind off the lesson for a short time. The technique was first developed in a school in North-East England and is gaining popularity in secondary schools throughout England.

The development of the technique, results of testing and its application are discussed together with the underlying neuroscience principles. The application of the technique to the specific task of teaching sixth form biology is examined and suggestions are made for ways in which spaced learning may be used to complement existing teaching techniques.

A field study was performed at a Swedish high school in order to assess the impact of spaced learning on education at this level. The study consisted of three spaced learning lessons delivered by the author and diagnostic testing. A survey was made to evaluate the student’s

opinion of spaced learning. The results were consistent with spaced learning working well for revision and the survey showed that the students were generally positive towards spaced learning and enjoyed the lessons.

This exam work is set out to make an objective appraisal of spaced learning and raises a major question over whether neuroscience discoveries can be used in the development of education or if the gap between molecules and cells, and the classroom is too great.

Contents.

1. Introduction.

1.1 My personal background to the project.

This project examines a novel teaching technique designed to enhance memorisation of lesson content and is known as spaced learning. The technique was designed on the basis of neuroscience research, investigating mechanisms by which memory is produced on a cellular level. I have worked and studied in medical or biological research and my career has taken a journey from studying cells and molecules to teaching biology and chemistry. My work involved studying a variety of biological systems and the common thread throughout this was to understand how biological systems function, at a cellular and molecular level. When thinking about education, I quickly became interested in the question of how much of the learning process (or at least factors influencing it) could be understood on a molecular, cellular, genetic or physiological level. Conversely, another interesting question is whether the growing body of knowledge generated by neuroscience can be applied to improving teaching.

An emerging scientific field known as neuroeducation (or educational neuroscience) is now attempting to address these questions (Ansari, De Smedt & Grabner 2012). The aim of neuroeducation is to allow neuroscientists and educationalists to work together in order to provide new and improved education. Much of the current focus in the field just now is on understanding the neurological mechanisms involved in reading, numerical cognition and attention, together with their associated dysfunctions of dyslexia, dyscalculia and ADHD. A possible problem with this approach is that the extrapolation between laboratory observations and the classroom maybe too great (Bruer 1997). Many researchers however, hold the view that this cross disciplinary approach holds much potential (Ansari, De Smedt & Grabner 2012) and progress is being made with specific learning difficulties (Gabrieli 2009).

Under my teacher training I became interested in the development of education and in different approaches used in teaching. I found an article describing spaced learning while searching for novel and innovative teaching techniques. This was published in the educational supplement of one of Britain's more serious newspapers (Woods 2009). It described a science class taking place in a sports hall, with school benches set up in one end. The lesson comprised of rapid PowerPoint presentations interspersed with short periods of physical activity, in this case dribbling basket balls. The method claimed to help concentration and memory, and to be based on recent neuroscience findings. It claimed that the technique enabled teachers to cover large quantities of content rapidly and led to better grades in exams.

I found spaced learning interesting for a number of reasons. After reading the article for the first time, it was easy to get the impression that this was the future of teaching. Teaching of factual content has become less popular with an emphasis currently being placed on deeper understanding. This technique lends its self to teaching factual material, although not necessarily restricted to this. I aim for promoting understanding in my teaching but see the need for this to be based on factual content. This is especially true in biology which contains much terminology. The idea therefore of teaching factual content in an efficient and painless way certainly has its appeal. There are claims made that individual students gained improved results (grades) after receiving spaced learning and of students passing the exam for a science module having received only ninety minutes of instruction using spaced learning (Curtis 2009). The claims initially sounded sensational and I was curious to examine these claims in greater detail.

I am interested in the question of whether we can design better approaches to teaching through advances in neuroscience or have centuries of education led to optimised teaching approaches through refining existing methods. Neuroscience is contributing to the understanding of specific learning difficulties. My hope is that in the near future, neuroscience

may help us to understand individual differences and may contribute to helping design education suitable for all. The spaced learning technique is an example of a teaching method based directly on neuroscience findings. It provides an opportunity to examine the possibilities and difficulties incurred in using such an approach. The spaced learning method raises questions of whether repetition is necessary or desirable in the learning process. I recall from my own education reasoning that if a term was only mentioned once, then it was probably of little importance and therefore easily forgotten. If a term is mentioned repeatedly however, it is likely to be relevant and therefore is retained. While spaced learning is not restricted to teaching factual material, the intense pace with which it is used implies that lessons have a high factual content. So is this a good method of learning factual material or is a more contextual setting necessary? Spaced learning can combine physical activity with teaching. The association between physical activity and academic achievement is well documented (Castelli et al 2007, Dwyer et al 2001) and this may have a positive effect on lessons. I was interested to see how well the method would work in a Swedish school. The thought behind this was that there may be unexpected differences in school culture between Britain and Sweden.

Spaced learning has often provoked a polarized view amongst teachers who either support or condemn it. I'll attempt to take an objective middle ground and look for ways in which it may be used to the best effect but also be critical where warranted.

1.2 Introduction to spaced learning.

This work examines both the theoretical background behind spaced learning and look at how it is applied. This technique is designed to promote long-term memory retention and is developed on the basis of results from neuroscience research. In practice, the technique involves dividing a lesson up into three periods of learning separated by two ten minute breaks. In the three learning periods, the same content is repeated (although the presentation

can vary). During the two ten minute breaks, the students are given an alternative activity that may take the form of a game or physical activity. The rational for this strategy is based on research performed by Fields (2005) and co-workers. They made an interesting observation when investigating memory at a cellular level, suggesting that long-term memory could be strengthened by repeated stimulation within a certain time frame.

This teaching technique was first designed and developed by Paul Kelley, a headmaster of a secondary school in North-East England. Kelley is known as an innovator, introducing later starts to the school day for his older students, based on the observation that teenagers work more effectively later in the day and supported by research into circadian cycles (Yang et al 2005). The design of his school contains novel features thought to help create an environment conducive for learning. These include letting high levels of natural light into the building and classrooms built with no parallel walls in order to reduce background noise. The spaced learning technique was first conceived by Kelley after reading Fields' article in Scientific American (Fields 2005). Douglas Fields reviewed evidence for how memory is formed at a cellular and molecular level. The central experiment used tissue samples taken from the hippocampus of rat brain that are active in long-term memory formation. For synaptic strengthening to occur, it was found that gene activation was necessary and newly synthesised proteins needed to be transported back to the synapse. This primes the synapse for further stimulation and provides a degree of strengthening. The process takes place in the order of ten minutes. Re-stimulation after this time leads to further synaptic strengthening, while stimulations within the ten minute period did not. Three such stimulations were found to be necessary for full synaptic strengthening. The receptive state of cells for re-stimulation lasts for thirty to forty minutes, after which it diminishes (Fields 2005). These observations suggested to Kelley, the basis for designing a teaching method. Assuming some of the same neurological pathways are used when repeating the presentation of a part of a lesson, it would

be possible to use the temporal framework that Fields (2005), described to present information in a repeated fashion in order to affect memory retention. Kelley attempted this and developed lessons consisting of carefully designed PowerPoint presentations that the teachers go through three times. These teaching periods typically take eight to twenty minutes. The first presentation consists of a straightforward albeit intensive presentation, the students listen and note taking is discouraged. The idea is that they concentrate fully on the presentation. The second presentation is similar to the first. The content and even the slides are repeated from the first presentation, with the difference that certain words are removed or questions inserted. These are then answered aloud by the class, either individually or collectively. PowerPoint animation is used to reveal the right answer. The third presentation typically consists of answering questions in a printed hand-out based on the PowerPoint slides. This gives the teacher a chance to talk to students about any problem areas on an individual basis. However, a PowerPoint with gaps and questions similar to the second presentation is still sometimes used. The three presentations are separated by two gaps of precisely ten minutes. These gaps are filled with activities that are different to the cognitive learning being undertaken, often a physical activity or game. The purpose of the gaps is to guarantee that time is allowed for the biochemical events to take place on a cellular level, that are needed to strengthen memory. The gaps may have other beneficial effects on learning and will be discussed later.

Spaced learning was never designed to be used in isolation and is combined with other teaching methods. It was initially used at the end of courses as a revision tool, prior to examinations (Bloom 2007). It may also be used at the start of courses as a means of introducing basic concepts before studying them at greater depth later in the course.

1.3 Newspaper articles discussing spaced learning.

The spaced learning technique received a degree of publicity between 2007 and 2009 after a number of newspaper articles were published discussing the teaching method. Early reports of spaced learning, described eight minute repeated lessons being given, with 10 minute breaks separating these (Bloom 2007). The so called “eight minute lesson” was widely discussed and provoked controversy. Criticisms directed towards spaced learning questioned if the technique led to learning raw facts rather than understanding, or if it was designed purely for passing examinations. Spaced learning appears to have been presented in a rather irresponsible fashion in the newspapers. The emphasis was often placed on sensational exam results and criticisms often pointed towards the limitations of teaching in this way. In experimental conditions, examinations were taken after students had only received one spaced learning lesson, resulting in unexpectedly high examination results (Marley 2009). This provoked a discussion about spaced learning replacing conventional teaching. In practice, spaced learning is used in combination with techniques such as enquiry based learning and project based learning (Bradley & Patton 2012) and not as a “stand alone” method.

The newspaper articles give some interesting insights into space learning classes in practice. One describes a science class taking place in a sport hall. Here, ten minute breaks are spent dribbling basket balls, before returning to desks and chairs at one end of the hall for a PowerPoint presentation (Woods 2009). It shows how light physical exercise can be combined with a science class. Also the article highlights how taking notes is discouraged as students are encouraged to focus and listen. Other activities used in the gaps include juggling, Sudoku, clay modeling and Chinese whispers. The actual nature of the activity is thought to be unimportant although it needs to be something that the class appreciates. There are repeated comments about positive atmosphere in the class. Students described the classes as fun and sounded motivated.

2. Background.

2.1 Spaced learning, spaced training and massed learning.

It is important to clarify some points concerning terminology which may otherwise cause confusion. The term “spaced learning” is used extensively in this work and refers strictly to the teaching method developed originally in a high school in England (Bradley & Patton 2012, Kelley & Whatson, 2013). Another term “spaced training” refers to learning episodes being repeated at various time points and is compared to “massed learning” where the learning episode takes place in a continuous block. Here there is much published work and the term “spaced learning” is sometimes used synonymously with “spaced training”. The terms “distributed practice”, “spaced repetition”, “spaced practice”, “spaced rehearsal”, “expanding rehearsal”, “graduated intervals”, “repetition scheduling”, “spaced retrieval” and “expanded retrieval” are also used in conjunction with spaced training, to add further confusion. Spaced training has been reported to result in better memory retention when compared to massed learning (Cepeda et al 2006). Spaced training can involve simple recall tasks for example, remembering items or verbal recall, in experimental situations. It can also be used in learning more complex theoretical concepts (McDaniel, Fadler & Pashler 2013). An example of where spaced training has been developed into teaching methods include the Pimsleur method for learning language, which uses the idea that learning can be optimized with a schedule of practice and gradually increases the length of intervals between presentations (Pavlik & Anderson 2008). A second example is the Leitner system which uses flash cards. Here the cards containing questions and answers are reviewed at varying intervals. Cards answered wrongly are attempted again after shorter time intervals while those answered correctly are left for progressively longer periods of time. Spaced learning is technically speaking, a form of spaced training. Here however, the inter-study interval has been set to ten minutes, rather than being determined empirically.

2.2 Memory.

The spaced learning technique was designed to enhance long-term memory and this will be discussed together with sensory, short-term and working memory. Memory is classified in terms of the nature of information remembered. Many psychological and behavioural observations and experiments have helped to develop and refine various theories and models of memory. Various neurodegenerative diseases and injuries of the nervous system support the idea that memory involves a number of independent systems that are responsible for different types of memory. A brief description other classifications and models will also be made with the aim of illustrating the diversity and complexity of memory. In simplistic terms, memory is a process where information is encoded (received and processed), stored (recorded) and retrieved (recalled for presentation or further processing). A model for memory containing three separate components was proposed by Atkinson and Shiffrin (1968). This was known as the multi store model (or modal model) and describes memory in terms of the movement of information. The basic components are the sensory, short-term and long-term memories and will be described in more detail below. Today, this model is looked on as an oversimplification, as what Atkinson and Shiffrin termed short-term memory includes working memory and in turn is divided into various processes. Similarly, long-term memory is divided into different components which depend upon the type of information stored. Examples of different types of long-term memory include “episodic” memory of events, “procedural” knowledge of how to perform tasks and “semantic” general knowledge. It is still viewed as a very useful and robust model on which to base further research.

2.2.1 Sensory Memory.

Information from our environment is received via our senses, namely sight, hearing, touch taste and smell. Sensory memory is associated with these senses and allows sensory

information to be retained for a short time before being passed on to the short term memory (discussed below). An example of sensory memory can be demonstrated with creating images by moving lights in a dark environment. Circles or letters can be drawn in this way which leaves a perceived image that rapidly disappears, (Baddeley, Eysenck & Anderson 2009: 7). The retention of sensory memory associated with sight (so called iconic sensory memory) has been measured to about 500 ms and is noted to decrease with age, (Walsh and Thompson 1978). Sensory memory is thought not to be under cognitive control or influenced by the level of attention given, but simply functions to briefly retain unprocessed information. Three types of sensory memory have been studied and are thought to operate independently of each other. Early research used timed recall of arrays of letters to estimate retention times for visual stimuli (Sperling 1960 and 1963). Echoic memory is the term given to sensory memory involving auditory stimuli. Darwin and co-workers performed analogous work to Sperling's research on iconic memory to provide evidence for echoic memory (Darwin, Turvey & Crower 1972). Haptic memory relates to the sense of touch and is beginning to be the subject of research. One preliminary report suggests that retention times for haptic memory to be in the region of one to two seconds (Shih, Dubrowski & Carnahan 2009). The senses of smell and taste are presumed to have similar distinct sensory memory systems. No reports have been found for such systems and they maybe not so amenable to testing.

2.2.2 Short-term memory.

The term short-term memory is a theory neutral way to describe the temporary storage of smaller amounts of information over shorter periods of time, in the order of seconds. Baddeley and co-workers note that the common use of the term short term memory can imply memory lasting a few hours or days. Strictly these belong to long-term memory and depend on the same processes as memories lasting for years (Baddeley, Eysenck & Anderson 2009). The retention time for short-term memory can be extended by active maintenance processes

such as verbal rehearsal. A second type of temporary memory is working memory and describes a memory storage used while processing and manipulating information. Parallels may be drawn to the computers “random access memory” in terms of its function. Commonly, the terms short-term and working memory are used synonymously. In the strict scientific sense they looked on as being separate concepts, although short term memory is thought to play an important role in working memory.

A frequently used test for assessing the capacity of short-term memory is that of memory span. This measures the items remembered and their order. The test involves presenting lists of items such as numbers, letters or words of progressively increasing length and assessing the individual’s ability to recall them. In a classic study, it was reported that about seven digits could be remembered (Miller 1956). The number of listed items that can be recalled from short term memory varies with choice of material. Letters lists that can be vocalized and divided into pronounceable pieces are more readily remembered. Chunking or dividing lists into smaller groups is a strategy used to remember information from longer lists or sequences. Telephone numbers are, for example, often remembered in groups of three or four numbers. Cowan claims that up to four chunks of information may be retained in short term memory (Cowan 2001). The retention time of short term memory is often quoted as up to twenty to thirty seconds. Estimates vary with different experimental approaches. Two hypotheses are used to explain how information is lost or forgotten from short term memory, namely it decays or that some interference occurs. Decaying implies that information that has not actively been processed or used in some way, will passively degrade. Interference can take the form of receiving information irrelevant for the task performed. The idea that pieces of information can compete with each other for limited space in a memory store is used as a model for interference. Retention times can be extended by mentally repeating or rehearsing information in order to re-enter it into the short-term memory.

2.2.3 Working memory.

Having looked at short-term memory which involves temporary storage of information without manipulation; working memory actively manipulates and processes information which can lead to decisions and actions and to information being committed to long-term memory. Baddeley and Hitch (2010) define working memory as "a limited capacity part of the human memory system that combines the temporary storage and manipulation of information in the service of cognition". It is thought to participate in reasoning, comprehension and learning. A multi-component model for working memory was proposed by Baddeley and Hitch (1974) consisting of an attention controller, the central executive and two slave subsystems, the visuo-spatial sketchpad which functions to store and process visual data and the phonological loop which operates with verbal and acoustic information.

The phonological loop is thought two consist of two components, a short term store and an articulatory rehearsal process. The store is assumed to be of limited capacity with memory traces decaying after a few seconds. The articulatory rehearsal process facilitates extended retention of memory traces by vocal or sub-vocal rehearsal (saying or thinking them). This model is consistent with much of the experimental data involving verbal short term memory. The visuo-spatial sketchpad (also referred to as visual short term memory) is a short-term memory for objects, shapes and locations. It is used to create and maintain visual representations needed for cognitive processes and is thought as the visual storage component for working memory. It can be subdivided into spatial (location) and object or visual (colour and shape) subsystems (Klauer & Zhao 2004). There is evidence supporting the visuo-spatial sketchpad storing movement sequences (Smyth & Scholey 1992). Central executive is proposed as a system capable of focusing attention on relevant information or processes while suppressing irrelevant information. Here, cognitive processes are coordinated between different systems including the phonological loop, visuo-spatial sketchpad and long-term

memory. In 2000, Baddeley elaborated the original model of working memory by adding a forth component, namely the episodic buffer. This is a form of memory allowing interaction between various working memory components and long-term memory (Baddeley 2000).

2.2.4 Long-term memory.

The basic model of memory being divided into a short-term and long-term system as described by Atkinson and Shiffrin (1968) is still generally accepted. Having examined short-term and working memory which can store a limited amount of items for up to 30 seconds and be readily recalled; long-term memory is argued to have a large and possibly limitless capacity and can retain information for a life time. Events with many associations and strong emotional influence are consolidated into lasting memories. Retention times in the range of minutes to hours are looked upon as long-term memory and follow the same process of encoding as information retained for longer periods of time. Items lacking relevant and meaningful associations are more readily lost and forgotten.

Different types of long-term memory have been categorized in terms of their content. Specific forms of memory impairment are observed in individuals having suffered traumatic brain injury suggesting separate forms of long-term memory which supports the idea of compartmentalization. Explicit or declarative memory refers to consciously available material. This is further divided into episodic memory which deals with events happening in a life time. Semantic memory refers to factual information for example words, concepts and knowledge in a broad and general sense. Baddeley includes examples such as the taste of a lemon or the colour of an apple and extends to knowledge of how society works for example, knowing what to do when you enter a restaurant (Baddeley, Eysenck & Anderson 2009: 11). The second major branch of long-term memory is implicit or non-declarative. This contains skills or behaviour learned but used on a subconscious level. Examples of skills learned here

are riding a bike or tying a shoe lace. They are classified under procedural memory. Once learned they are performed without thinking. Conditioned behaviour or habits also operate in implicit memory. Priming is the term used when a given stimulus influences a response to a later stimulus. As example, we can consider a test where a subject is given a list of words. If later they are asked to name words beginning with a specific letter, they are most likely to include words that fit from the list, even if they have not consciously memorized the list. Amnesic patients can often perform tasks requiring implicit memory and this is taken as evidence for explicit and implicit memory operating from different systems (Brooks & Baddeley 1976). Emotion can have a strong influence on long-term memory (Hamann 2001). It is thought to influence both explicit and implicit memory.

2.2.5 Memory consolidation.

The notion that fixed memories can take time to establish has long been observed. As far back as Roman times, Quintillian stated “that a single night’s interval will greatly increase the strength of the memory” and suggested that “the power of recollection undergoes a process of ripening and maturing”. The term consolidation was introduced by Müller and Pilzecker in the late 1800’s (reviewed in Dudai 2004). Memory consolidation is a term given to time dependent processes involved in stabilizing a temporary memory trace or engram after it is initially encoded. The term is used in two ways, namely systems consolidation, involving memory transfer within the brain and synaptic consolidation referring to changes at a cellular and molecular level resulting in synaptic strengthening. A number of models have been proposed for systems consolidation. The standard model proposed by Frankland and Bontempi (2005) states that new information becomes initially encoded in the hippocampus and cortical regions. The hippocampus is thought to retain this information and slowly transfer it by both the help of conscious recall and subconscious processes. Sleep is thought to be important for this process with evidence supporting the need for rapid eye movement sleep

in order for consolidation (Walker et al 2005). However other studies showed that sleep deprived patients (having no rapid eye movement sleep) showed no defect in task learning (Vertes 2004). Synaptic consolidation is modeled on synaptic plasticity and long-term potentiation and will be discussed in the section below.

2.2.6 Neurological basis of memory.

Donald Hebb proposed that “long term learning depends on the creation of cell assemblies”. He speculated that connections are made between synapses of two or more cells that are excited at the same time (Hebb 1949). Repeated firing of such cells is thought to lead to changes in the chemistry in the synapses leading to strengthened connections. Hebbs theory is often summarized as “cells that fire together, wire together”. Hebb’s postulates remain influential today as increasing evidence has been found in support of them. Bliss and Lomo (1973) found that repeated stimulation of an axonal pathway resulted in increased potentials (signal strength) and called this long-term potentiation. Such prolonged strengthening of synaptic transmissions involves both increases in production of neurotransmitter substances and receptor responsiveness and is referred to as synaptic plasticity. Long-term potentiation occurs in various parts of the brain but for long-term memory formation, predominantly occur in the hippocampus. On a molecular level, a pathway involving N-methyl-d-aspartate (NMDA) receptors, calcium ions, cyclic adenosine monophosphate (cAMP) and cAMP-response element binding protein (CREB) is a major route to memory formation (reviewed in Malenka & Bear 2004). This ultimately leads in a program of gene activation resulting in changes in the synapse. This gives rise to the molecular changes needed for a synapse to exhibit long-term potentiation. This scenario is supported by evidence provided by using pharmaceutical agents antagonizing the activities of NMDA receptors, cAMP formation, CREB and protein synthesis. These are shown to block memory formation.

2.3 Learning.

Learning involves changes in our state of knowledge, skills, behaviour, emotions and values. This may entail conceiving something new, or modifying, or reinforcing pre-existing qualities. Humans, animals and even some computerised machines have the ability to learn in some respect. Learning can be looked on as a process in which existing knowledge is changed by the interaction with new experience and with the environment. The changes produced in learning are relatively permanent and memory is integrated intimately in this process.

Learning may take place in various situations. Formal learning takes place in an organised and goal orientated manner typically within the education system. Informal learning considers everyday situations such as play, exploring and social interactions. Enculturation is the process by which a society's cultural values are learned and includes values, language and rituals. Episodic learning describes where a significant or traumatic event strongly influences a person's life. Rote learning is a teaching technique aimed at memorising information, although not necessarily understanding it. It is based on repetition and aims to allow the learner to be able to immediately recall what they have learned. Examples include learning multiplication tables in mathematics and catechisms for teaching religious doctrine. It is criticised when used in isolation due to the lack of understanding it imparts. Critics of spaced learning have compared it to rote learning, claiming that too much emphasis is placed on factual information and too little on understanding. Spaced learning uses repetition to help commit information to memory and this may be of a predominantly factual nature. The aim is however, to use this as a basis for contextual learning and understanding. In contrast to rote learning, meaningful learning is the term given learned knowledge is related to other knowledge to provide a full contextual understanding. Active learning happens when individuals take control of their own learning and involves self-assessment of what they have learned and decisions about what to learn. This leads to incentive and motivation to learn.

This is not an exhaustive appraisal of learning but an attempt to illustrate that there are many routes to learning. Some routes may suit certain individuals better than others and some learning situations maybe unavoidable but understanding depends on contextualising what is learned.

3. Spaced learning in practice.

3.1 Practical requirements.

Spaced learning lessons are usually delivered using a PowerPoint presentation, so a class room with a projector is required together with a computer. A large classroom with the possibility to rearrange desks in order to provide space is needed if some form of physical activity is planned for the gaps. Alternatively, a classroom with easy access to get outside will allow for a physical activity to take place outdoors.

3.2 Can all subjects be taught using spaced learning?

Spaced learning was initially developed using biology, other sciences and technical subjects. These subjects maybe particularly suitable for spaced learning due to the amount of terminology they contain. Most testing has been performed on such subjects. The method has been attempted with a range of subjects, including English, history and mathematics; although no formal testing has been reported in such cases. Spaced learning should, in theory, help for any type of learning that involves a high degree of memorisation. It may not be an optimal technique for all subject matter however. Complex theoretical areas may be better served using other teaching strategies aimed at overcoming conceptual hurdles, although spaced learning may still have a role where much factual material needs to be introduced. Mathematics requires problem solving in combination with theory. Although spaced learning has been attempted in this subject, it may not be so advantageous to learn large quantities of mathematical background in a short space of time.

3.3 Activities to occupy the gaps.

The idea behind the ten minute gaps is to allow time for the relevant synaptic connections to rest and to undergo the biochemical processes needed to strengthen them. There is no way of guaranteeing or controlling this happening. In practice, the class is given an activity, which is assumed to utilise other neural pathways and hopefully be enjoyable. Initially, Kelley and colleagues tried giving small exercises from other subjects (mathematics and chemistry) or using microscopes in the gaps, but these did not prove popular. Physical activities were tried next as many correlations between exercise and academic achievement had been shown (Castelli et al 2007, Dwyer et al 2001). While regular exercise was found to be beneficial for educational performance, it is not clear if combining exercise immediately with teaching is beneficial. Examples of physical activities used include juggling, simple ball sports, dribbling basket balls, simple team games and taking short walks. These proved popular with the students. Such activities can be hard to apply and depend on the physical classroom size and access to get out doors. They need to be applied within strict time restrictions. Other activities such as Sudoku or clay modelling are also used, while older students simply make coffee. Interestingly, a recent paper provides evidence for long-term memory being enhanced by a short (ten minute) wakeful rest being taken after learning (Dewar et al 2012).

3.4 Observations from spaced learning lessons.

I participated in a demonstration of a spaced learning lesson that was given during a teaching conference (Gittner & Kelley 2012) and was attended by twenty five teachers. Here the mechanics of a spaced learning lesson was explained and a short demonstration lesson was given. The lesson was about materials and textiles used in clothing, for example Gore-Tex. The presentation was fast but easy to follow. Some guidelines were suggested for the optimal tempo of presentation and PowerPoint slides were changed about every 30 seconds. Juggling tennis balls was attempted during the ten minute break. While there were obviously no

talented jugglers in the group, the activity was conducted in a light hearted manner and worked perfectly as a distraction from the lesson. The second lesson followed the same set of PowerPoint slides as the first, but with key words missing. Individuals were systematically asked to provide the missing words as an attempt to test memory and were generally answered enthusiastically. The presentation was strongly orientated towards delivering information rather than explaining any underlying ideas. It was still impressive to see how a relatively intense presentation could be delivered in such a clear and coherent manner. A second pause and third teaching period was not used in this demonstration lesson.

In order to experience a classroom atmosphere during a spaced learning lesson, I organised a visit to an English high school and observed a spaced learning lesson. A class in the age range of fourteen to fifteen years received a spaced learning lesson on the subject of atomic structure. The presentation covered the structure of the atom in terms of electrons, protons and neutrons. It included discussion of atomic number, atomic mass and isotopes. The class had some background in this area and the lesson was aimed to clarify and expand ideas about atomic structure. The classroom was organised with two rows of chairs at the front, allowing space for a game further back in the class. The students were reasonably well organised having previously taken spaced learning classes. The first teaching period was based on a clear structured PowerPoint, building models of atomic structure and finishing with a number of examples for different elements. Even here the class was surprisingly interactive and time was found for answering a number of questions put forward by the class. A team game involving passing balloons was used in the ten minute break. It appeared to engage the competitive nature of the class. The second teaching period again was based on the same PowerPoint. However, the questions were based on solving problems in addition to direct memory recall. Some questions spilled over into discussion and the atmosphere of the classroom was very active and engaged. The balloon game was repeated for the second break.

In the third teaching period, the students were given a hand-out containing questions based on the presentation. This allowed time for individual help to be given by the teacher. The two previous presentations had ran over time and the hand out was completed it at home. This is a strategy commonly used to allow some flexibility in lessons. On reflection, the lesson appeared to work very well and showed that a spaced learning format can be used to present good lessons.

4. Study of spaced learning made in a Swedish High School.

4.1 Design of study.

The present investigation has been designed as a pilot study with the aim of assessing how spaced learning can be applied to a Swedish High School science course and to provide guide lines for how a more extensive study could be designed in the future. A study using parallel classes in which spaced learning could have been compared to conventional teaching alone, under controlled conditions, would have been ideal. However, a single second year class from a science programme (naturprogram) of twelve pupils was made available for the study. This dictated that a qualitative study could be made. Two spaced learning classes were initially planned. One lesson involved basic cell function and was planned to provide revision of subject matter already covered, prior to an exam. The second lesson covered a biochemical part of a chemistry course and involved lipids. It was designed to provide a conceptual framework and introduce necessary terminology prior to conventional teaching of the subject. A third lesson was used to introduce concepts of how we defend ourselves against diseases and of basic function of the immune system. This was given prior to formal lessons in immune function.

4.2 Methods.

4.2.1 Introductory talk.

I gave a short introductory talk to explain the aims of the project and what form the lessons would take. Spaced learning was described as a teaching method designed for enhancing long-term memory and was developed from observations from neuroscience. The structure of a typical spaced learning class was outlined.

4.2.2 Content of the cell function lesson.

I presented the three spaced learning lessons described below. The aim of the first lesson was to examine some ideas of basic cell function and introduce relevant terminology. Focus was placed on organelles and function including the mitochondria, nucleus, ribosome, endoplasmic reticulum, Golgi apparatus, lysosome, peroxisome, cell membrane, flagella, cytoplasm and cytoskeleton (see Appendix 1). A description of electron microscopy had not been given earlier in the course, which was unfortunate as this could have provided an excellent platform to introduce organelles. Plant and fungal cells were discussed in terms of differences and similarities to animal cells and characteristics shared between eukaryotic cells. The presence of both mitochondria and chloroplasts in plant cells was emphasised, illustrating that both respiration and photosynthesis occur here. This is often a point of misunderstanding. The nucleus was referred to in terms of housing the cells genetic material and being the site of transcription. Structurally, the nucleus was described as having a double membrane or nuclear envelope, in contrast to single membrane organelles. Nuclear pores where mentioned to highlight mRNA transport from the nucleus to the cytoplasm. The connection between the nuclear envelope and the endoplasmic reticulum was used to illustrate the idea that the two were in close proximity. No reference to transport between the endoplasmic reticulum and the nuclear envelope was made. Ribosomes were described as the

sites of protein synthesis or the cell's protein producing factories. No models were given for how ribosomes work, for example A, P and E sites and large and small subunits were not discussed and were planned to be taken up later in the course. The idea that translation could take place on free or membrane bound ribosomes was introduced together with the effect this could have on eventual protein localisation. This also serves as an introduction to the rough endoplasmic reticulum. On a structural level, some weight was placed on the notion that the ribosome provides an example of a macromolecular complex and in contrast to many other organelles, it does not possess a membrane. The structure of the cell membrane was described in terms of a phospholipid bilayer in which functionally active membrane proteins where imbedded (see slides on p. 59). Both the rough and smooth endoplasmic reticulum were described as functionally distinct regions of the same organelle. An outline of protein secretion and vesicular transport was given describing the pathway taken by proteins destined for the cell membrane or for secretion (see slides on p. 61). Mitochondria and chloroplasts were viewed as organelles responsible for energy conversions. The idea that they originated from a prokaryote living in a symbiotic relationship was briefly discussed. The basic components of the cytoskeleton, namely microtubules, microfilaments and intermediate filaments, were discussed. Structure and function of cytoskeletal components was given, however it was difficult to illustrate the dynamics of cytoskeletal function under the time restraints of a spaced learning lesson. The concepts of extracellular matrix, cell-cell interactions and signal transduction were introduced. The extracellular matrix was described as a network of proteins in close proximity to cells in a tissue. Interactions between cells and the extracellular matrix via adhesion molecules were alluded to. Tight junctions were described in a purely functional manner as connections between cells that prevented the passage of liquid. Connections between cells containing intermediate filaments and providing mechanical support were also described although the term "desmosome" was not introduced

here. It was decided to present models of signalling to cells via membrane bound and steroid receptors (see slide on p.63). General pathways were outlined in which signal substances produced from surrounding cells would interact with receptors on target cells and eventually lead to activation of a specific set of genes. On reflection, this scenario demanded the integration of a number of new concepts that may not have been fully understood. An alternative would have been to introduce signal transduction in conjunction with a familiar signalling system, a hormone for example. This could have provided a context for understanding the signalling system.

4.2.3 Content of the lipid lesson.

A section of the chemistry course deals with biochemistry or “the chemicals of life”. This covers the major headings of proteins, carbohydrates, lipids and nucleic acids. The second lesson presented was a part of this course and concerned lipids (see Appendix 2). The aim here was to introduce and familiarize the class with concepts, examples and terminology surrounding lipids. The class had received no formal education concerning lipids so this lesson was a preparation for a deeper coverage of the subject in subsequent lessons. The students had covered relevant basic organic chemistry including alkanes, hydrophobicity, solvent solubility, alkenes, double bonds and esterification reactions. So it was assumed that they should have some relevant background. A description rather than a definition of lipid was given, emphasising that they are a diverse group of natural products that are fat soluble and water insoluble, rather than having a defining chemical characteristic. Examples of lipids in the form fats, fatty acids, phospholipids, steroids and waxes were provided to illustrate diversity and hydrophobicity in lipids. A closer look was taken at the formation and structure of fats. After a reminder about esterification, the formation of fats by ester bonds between fatty acids and glycerol was illustrated. A variety of common fatty acids were shown to illustrate different lengths and how the introduction of double bonds can affect their physical

properties (see slides p.65). The physiological functions of fats were discussed together with the growing problem of overweight and obesity. The basic structure of phospholipids was examined, with emphasis being placed on the hydrophilic and hydrophobic sides of the molecule rather than exacting chemical details. The cell membrane was used to illustrate phospholipid bilayer structure. Membrane proteins and their possible functions were discussed together with the presence of cholesterol in the membrane. Carbohydrate structures were briefly mentioned with no reference made to terms such glycoproteins or glycolipids. The underlying message was to relate the structural features of the cell membrane to function. Saponification, the basic hydrolysis of fats to produce soap, provides a good example of how surfactants behave in water. Micelle formation illustrates how soaps can suspend hydrophobic material in water. Micelle structure may also serve as a model to help explain how phospholipids behave in membranes. Cholesterol and two steroid hormones (estradiol and testosterone) were shown to provide examples of steroid compounds and to illustrate their characteristic structure. Here the aim was to familiarise students with the four ring structure of steroids rather than detailed structure. A number of structures of fat soluble vitamins were given together with a brief discussion of essential fatty acids (see slides p.68-69.). The underlying point was that there is a dietary requirement for certain fat soluble components.

4.2.4 Content of the immune defences lesson.

The aim of this presentation was to illustrate different strategies used to prevent or to fight infections in the human body (see Appendix 3). To introduce the subject, the question of how we get infected was posed and examples of bacterial and viral derived diseases were discussed while fungal agents and parasites were briefly mentioned. Various routes of infection were examined. Traditionally the immune system is divided into innate and adaptive sections. This division is artificial as there is much interaction, interplay and interdependence between the two systems. It does however help by dividing a complex, multicomponent

system into smaller functional units that maybe easier to conceive (see slides p.71). As an overview, the innate immune system was described as a general protection against infection, with the skin acting as a first line of defence and phagocytes as a cellular defence. To convey the idea of an adaptive immune response, the production of antibodies to a specific antigen was described. The innate immune system was described in more detail. In addition to the skin, the idea was introduced that other barriers could help prevent pathogens entering the body. These include mucous membranes and acidic gastric juice and use enzymatic secretions and low pH respectively against infectious agents. The topic of cellular defences was expanded to include a description of phagocytosis and while the function of NK cells as a way to destroy virally infected or abnormal cells was briefly outlined. The characteristics of inflammation were discussed, together with elevated body temperature as a means to fight infection. Finally, a simple model of interferon's roll in prevention of viral infection was shown. Expanding on the adaptive immune system, T-cells were introduced and the idea that they have a mechanism to detect antigens found inside cells was proposed. This was probably one of the more difficult ideas in this presentation. The idea of T-cell function was unfamiliar to most of the students and presenting a coherent model would demand a better background than they had. The involvement of T-Cell receptors and cell-cell contact was outlined. Any mechanism involving antigen presentation was left unexplained, for although vesicular transport mechanisms had been discussed earlier in the course, they were not well understood. The T- and B-cell antigen receptors were compared with emphasis being made on the variable domains and how they lead to the recognition of different antigens (see slides p.74-75). The point that B cell receptors or antibodies recognise antigen in the extracellular fluid and that T-cells recognise intracellular antigens was made. To exemplify T-cell function, cytotoxic T-cells were shown to kill infected or sick cells in a process involving cell-cell contact and the T cell receptor.

In addressing the question of what do T-helper cells do, they were described as having a regulatory role in activating B cells to produce antibodies. The cellular mechanism of “T-cell help” is a complicated scenario with interactions between T-helper cells and Antigen Presenting Cells and between T-helper cells and B cells. This subject was described very superficially. Finally, lymph organs and lymph vessels were discussed to show how lymphocytes re-circulate through the body and to get a perspective of the immune system in its entirety.

4.2.5 Diagnostic tests.

Diagnostic tests were designed to assess recall and understanding (see appendix 4). They consisted of thirteen short questions in the case of the first two lessons and eight questions for the third (immune defence) presentation. They were planned to take about ten minutes to complete (although no formal time limit was given) and cause the minimal disruption of class. No forewarning was given prior to the tests so no special preparation was made. The tests were anonymous as the overall performance of the class was of importance rather than that of individuals. The same test was given on three separate occasions. The first (pre-test) was taken immediately prior to the spaced learning lesson in order to assess prior knowledge of the subject. This was one to seven days prior to the lesson. The test was repeated one to two weeks after the lesson and again at a time point two months after the lesson.

4.2.6 Survey.

A survey was made in order to assess how students experienced spaced learning lessons, if they felt the lessons helped in learning and to provide an opportunity to comment on this method of teaching. The survey consisted of twelve questions or points and was given out two weeks after the first diagnostic test (see Appendix 5). The students were asked to write these in their own time and completed forms were collected one week later.

4.2.7 Teacher interview.

An interview was conducted with the teacher responsible for teaching both biology and chemistry for the class studied. The teacher was present in the lessons and fully involved in the choice of content of the lessons. The interview was aimed to address basic questions concerning spaced learning's effect on memory and understanding. Activities used in the breaks were also examined. The teacher presented his own lesson using spaced learning and reflected on this. Finally the questions of how and if neuroscience can be used for designing teaching strategies, was approached. The interview was recorded and a transcript made of this. A summary of the interview is provided in the results section below.

4.3 Results.

4.3.1 Presentation of lessons.

The following section is a summary of how well the lessons met their objectives and of problems that were incurred. The three spaced learning lessons described above were presented to the class by the author. The first observation to make was that the lessons felt stressful. It was difficult to present the planned material in the allotted time frame. This may simply have been due to the amount of content presented and the author's relative inexperience as a teacher may also have contributed as it clearly takes skill to present both quickly and coherently.

The second teaching period of a spaced learning lesson included asking simple questions to help information recall. The class was encouraged to answer aloud. This was attempted in the first lesson (cell function) but without success. The entire class appeared shy and introverted, and were reluctant to answer aloud. Interestingly, the regular teacher constructed a spaced learning lesson. When he presented this, the class far more interactive and prepared to answer questions, suggesting that it is important to have a teacher that the class is familiar with. This

raises the question of whether a different outcome could have been obtained if the regular teacher had delivered the three spaced learning lessons in this study. In the second and third lessons, a strategy of setting questions and providing explanations was adapted in place of questioning the class.

A number of ambitious ideas were discussed concerning what to do in the ten minute gaps. These included using microscopes to observe or draw something of biological interest; the idea behind this being that the activity was unrelated to the lesson while contributing something meaningful to the students education. Another idea was a short tips promenade in order to introduce light exercise into the lesson. Eventually it was decided to use Sudoku which was popular with the students and clay modelling with a biological theme. These activities had the advantage of being fast and easy to organise under strict time restraints.

4.3.2 Diagnostic test results.

All twelve students participated in both the spaced learning lesson which concerned cell function and in the diagnostic tests. Figure 1 shows a graphical representation of the collated data from the pre-, first and second tests.

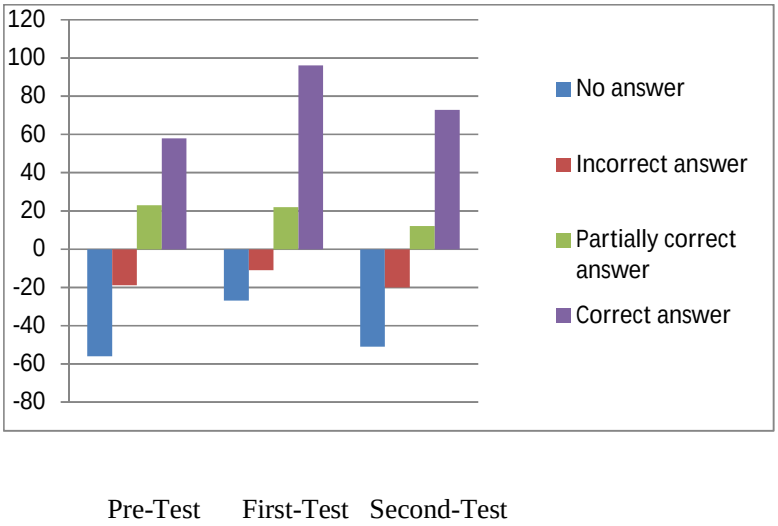
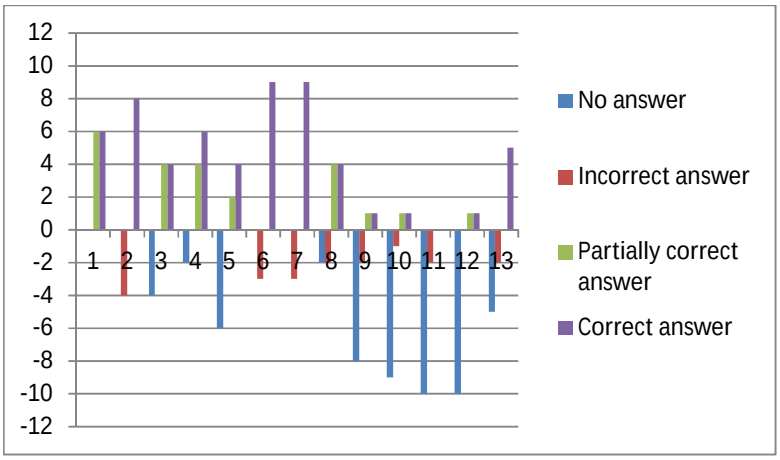


Figure 1. *Summary of collated results from the diagnostic testing used for the cell function lessons.* Answers to questions are categorized as no answer, incorrect answer (both represented as negative values for display purposes), partially correct answer and correct answer and are a summation of the test. The y axis shows the accumulated answers for each category. The results from the pre-test, first diagnostic test and second diagnostic test are shown as indicated.

The pre-test showed that many pupils had some background knowledge relevant to the lesson. Although no preparation was made for the pre-test, it was hoped that many questions could be answered from coverage in the preceding lessons. This indeed appeared to be the case. The results from the first diagnostic test showed an increase in correct answers from 58 in the pre-test to 96 in the first diagnostic test. The results from the second diagnostic test showed a decrease in correct answers as compared to the first diagnostic test (96 correct answers in the first diagnostic test compared to 73 in the second diagnostic test) indicating the best test performance is achieved soon after the spaced learning lesson. An increase was in unanswered questions was seen when comparing the first and second diagnostic tests (27 unanswered questions in the first diagnostic test compared to 51 in the second). Long-term memory requires consolidation processes in order to commit information to memory over longer time scales, so presumably this is following a forgetting curve.

In Figure 2, the responses to individual questions in the respective diagnostic tests are examined.

A



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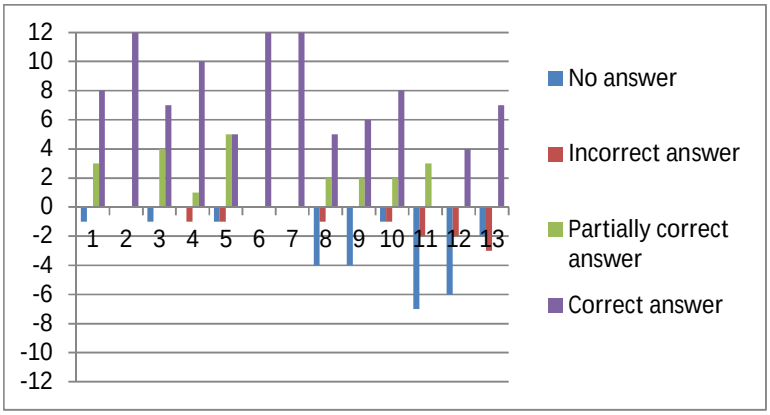


C

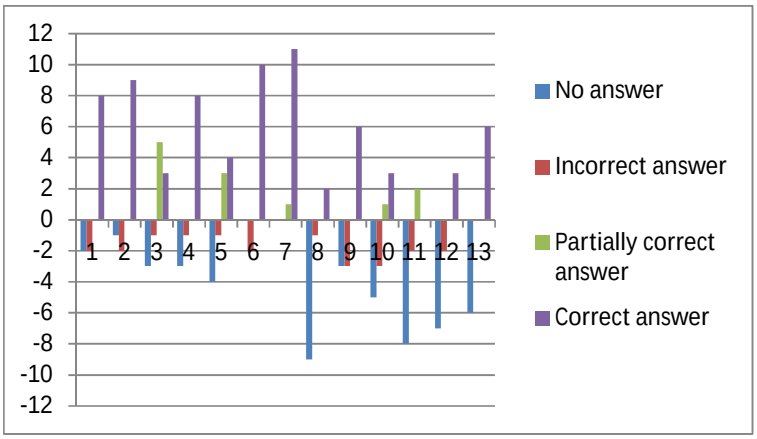


Figure 2. *Comparison of results from individual questions from the diagnostic testing given in association with the cell function lesson.* Answers to questions are categorized as no answer, incorrect answer (both represented as negative answers for display purposes), partially correct answer and

correct answer for each question. The y axis shows the number of answers for each category and the x axis shows the question number. *A* represents the pre-test, *B* the first diagnostic test and *C* the second diagnostic test.

When examining answers to individual questions relating to the cell function lesson, the questions relating to organelle function (questions 3 to 7) were generally answered well (Fig. 2 B and C). Questions 9 to 12 were more technically demanding and concerned cell signaling and organelle structure. These questions were often not attempted in the pre-test. A clear improvement was seen in the first diagnostic test (Fig. 2B). Interestingly, the same questions were frequently left unanswered in the second diagnostic test (Fig. 2 C) suggesting that they were the first to be forgotten and may indicate differences in learning general versus detailed knowledge by spaced learning.

Again, all twelve students participated in both the spaced learning class involving lipids and in the corresponding diagnostic tests.

Unfortunately a high proportion of unanswered questions were found throughout the testing. There may be a number of factors contributing to this. Firstly, the student's background may have been misjudged. It was assumed that hydrophobicity and the physical properties of organic molecules were covered earlier in the course. This may not have been the case. The content of the lesson may have been at a too advanced level, although nothing went beyond what is found in current textbooks. Finally, the intense nature of a spaced learning lesson may not have been appropriate for introducing a subject in which students have very little background. On a more positive note, the numbers of correct and partially correct answers increased from 22 to 65 and 73 from the pre-test to first and second tests respectively (Fig.3). Interestingly, an increase was seen when comparing first with the second test. Students received formal tuition and a course exam in between first and second tests so an increased test score in the second test could be expected.

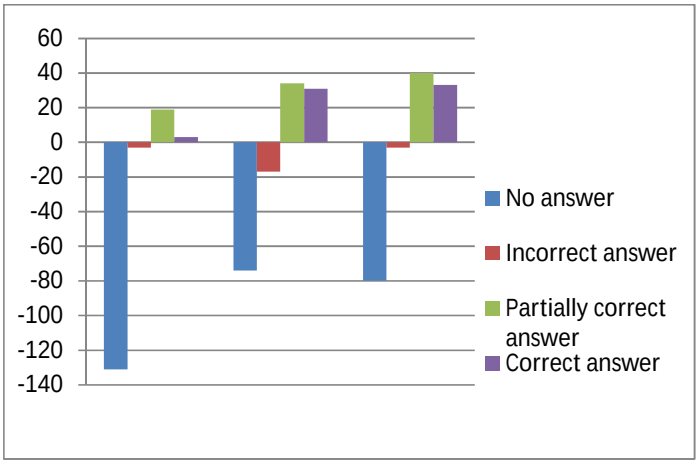
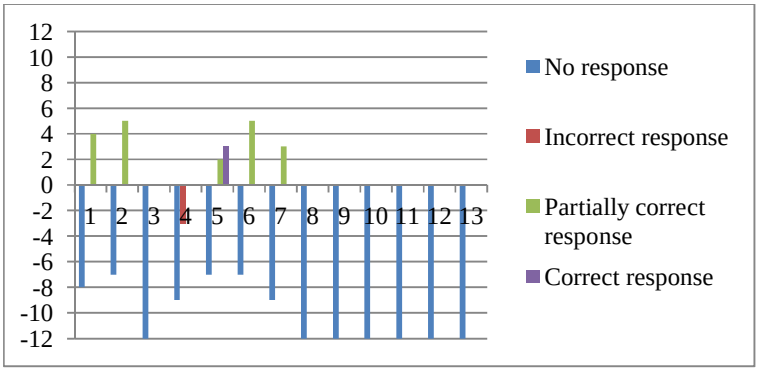


Figure 3. *Summary of collated results from the diagnostic testing used for the lipid lessons.* Answers to questions are categorized as no answer, incorrect answer (both represented as negative answers for display purposes), partially correct answer and correct answer and are a summation of the test. The y axis shows the accumulated answers for each category. The results from the pre-test, first diagnostic test and second diagnostic test are shown as indicated.

A



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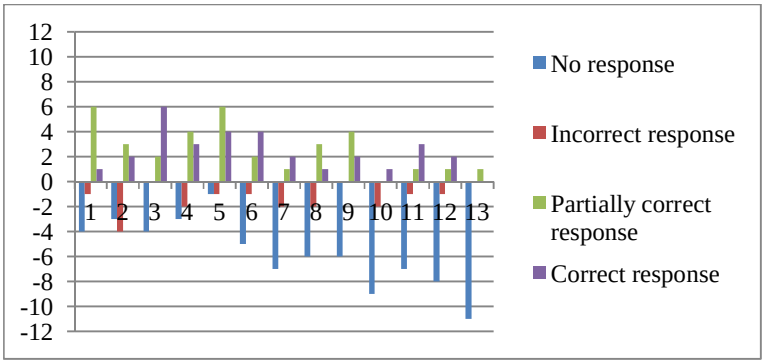

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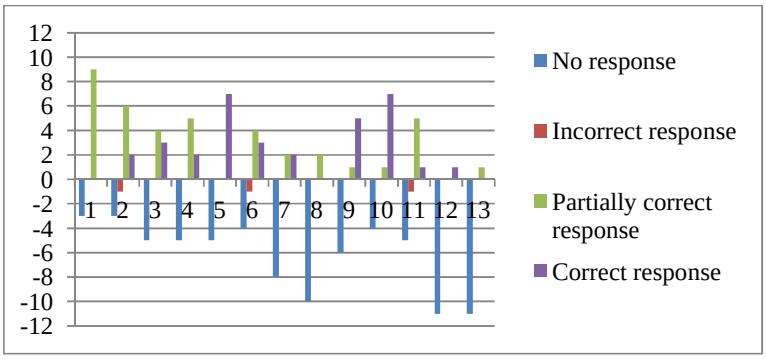


Figure 4. Comparison of results from individual questions from the diagnostic testing given in association with the lipid lesson. Answers to questions are categorized as no answer, incorrect answer (both represented as negative answers for display purposes), partially correct answer and correct answer for each question. The y axis shows the number of answers for each category and the x axis shows the question number. *A* represents the pre-test, *B* the first diagnostic test and *C* the second diagnostic test.

Problems were experienced with many questions in this section (Fig. 4). Descriptive questions such as discussing the physiological of function fat (question 5), were generally answered better than more factual questions.

A spaced learning lesson was given on immune defences as an introduction to the subject (no tuition had been previously given on the subject). A pre-test and one diagnostic test were given. Unfortunately, it was not possible to schedule a second diagnostic test. Ten and eight students were present for the pre-test and diagnostic test respectively. Percentages will therefore be quoted for the purpose of comparison. In the pre-test, two questions were answered from general knowledge and concerned ways to prevent infection and the characteristics of inflammation. The diagnostic test was performed with a mean score of 50% correctly answered questions, in comparison to 17.5% in the pre-test (Fig.5). This was possibly a good result, considering that the lesson was both intense and technically demanding.

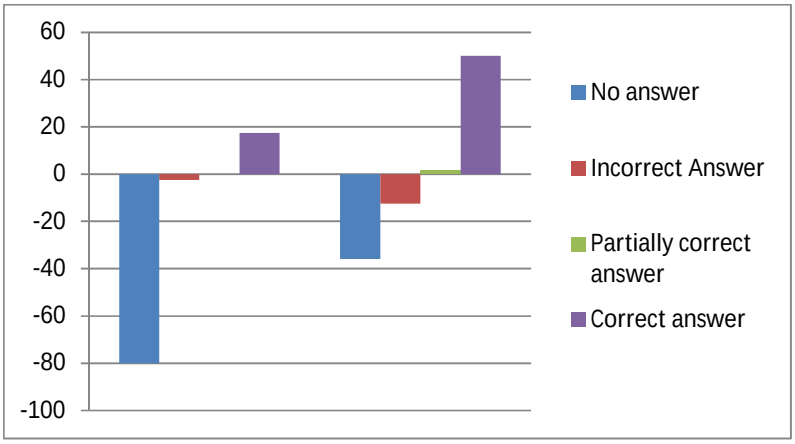
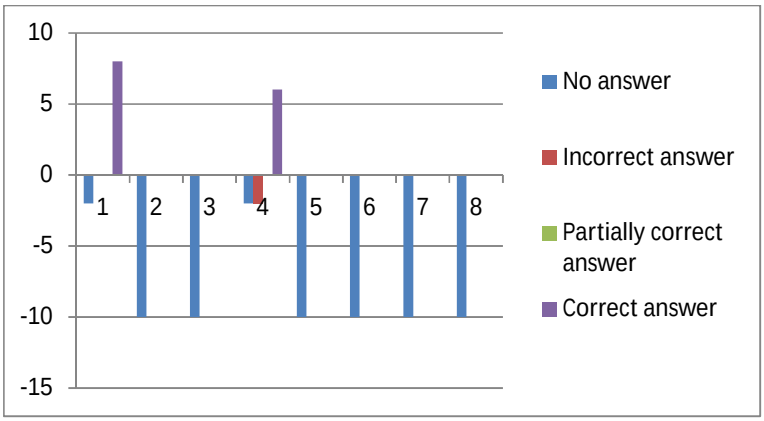


Figure 5. Summary of collated results from the diagnostic testing used for the immune defense lesson. Answers to questions are categorized as no answer, incorrect answer (both represented as negative answers for display purposes), partially correct answer and correct answer and are a summation of the test. The y axis shows the accumulated answers for each category and are shown as percentage values of total score. The results from the pre-test and diagnostic test are shown as indicated.

A



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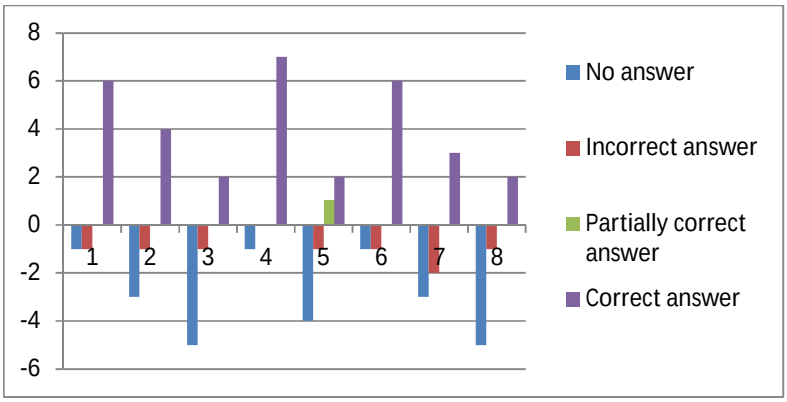

Figure 6. Comparison of results from individual questions from the diagnostic testing given in association with the immune defence lesson. Answers to questions are categorized as no answer, incorrect answer (both represented as negative answers for display purposes), partially correct answer and correct answer for each question. The y axis shows the number of answers for each category and the x axis shows the question number. *A* represents the pre-test and *B* the diagnostic test.

Some good explanations were provided for immune memory (question 6). There were however, three questions that many students failed to answer. The first concerned the role of lysosomes in phagocytosis (question 3). This was slightly surprising as lysosomes had been discussed previously and appeared to be well understood. Question 5 asked about antigen recognition and was probably too demanding. T-cell antigen recognition is described in current biology textbooks but is still ignored my many teachers. Finally, question 8 concerning the lymphatic system was problematic and it is possible that too much material was covered by a single slide, on this occasion.

4.3.3 Survey findings.

The aim of the survey was to find out what the students thought about the spaced learning lessons. Specifically, it was interesting to find out if the lessons worked and could be used as an alternative approach to teaching and also if they were enjoyed. Some questions were designed to assess whether spaced learning promoted understanding and memory. The survey provided an opportunity for students to voice criticisms of the method or its application.

The survey was anonymous and distributed amongst the entire class of twelve students, who were instructed to complete it in their own time. Nine completed replies were returned and form the basis of this survey. The original survey questions which are in Swedish can be found in Appendix 5.

The first five questions were used in a semi-quantitative approach to measure opinion. The questions required replies on a scale of “agree completely”, “agree”, “unsure”, “disagree” and “disagree strongly” and were scored from five to one respectively. The questions and answers are presented in Table 1. Questions one to four provided positive statements about spaced learning. The majority of students agreed or strongly agreed with the statements. Nobody disagreed with them. Four completely agreed with the notion that spaced learning is a good way to revise and three with the statement that it complements other teaching techniques. There was good agreement with the idea that the technique is a good method for introducing new concepts and promoting understanding. Question 5 puts forward a negative statement and asks if the lessons were too intense and difficult to follow. There was a mixed response to this question and answers to questions in later parts of the survey indicated that some students found that the lessons could be too intensive.

	Agree completely	Agree	Unsure	Disagree	Disagree strongly	Mean score
(Score weighting)	(5)	(4)	(3)	(2)	(1)	
1. Spaced learning is a good method to introduce new concepts.	1	8	0	0	0	**4,1**
2. Spaced Learning helps to provide a good understanding of what is being taught.	1	6	2	0	0	**3,9**
3. Spaced learning is a good way to revise for a test.	4	5	0	0	0	**4,4**
4. Spaced learning works well to complement other teaching techniques.	3	6	0	0	0	**4,3**
5. Spaced Learning lessons were too intense and difficult to follow.	0	2	3	2	2	**2,6**

Table 1. Semi-quantitative survey to indicate how students experienced spaced learning.

Seven questions were then given that the students were invited to answer in their own words. Firstly the students were asked to describe what they understood about the teaching technique "spaced learning". This was to control for any misunderstandings concerning the technique. All answers referred to teaching involving repetition, while seven mentioned pauses. Impressively, two detailed answers referred to the subject of synapses, which was only referred to briefly in a short introductory presentation. All replies showed some understanding of what spaced learning involved and none suggested misunderstandings. The next question asked “do you feel spaced learning helps you remember what was taught?” Assisting memorization was one of the fundamental claims of spaced learning so it was interesting to see if the pupils felt that the method helped with this. Eight answered “yes” of which four made the proviso of “but not everything” or “the most”. There was one answer of “a little”. The consensus of the class was that they thought the method helped memory. The next question asked if the method helped in understanding of how biological systems work. The idea behind this question was to assess whether the students thought that spaced learning could contribute to deeper understanding as opposed to simple factual recall. The question did not demand any explanation and three students answered “yes” and six responded “a little”. It appears that it was not obvious that spaced learning is thought to help understanding. The

question of using repetition of presentation of material in lessons was examined and the students were asked whether this helped learning and if receiving repeated information was irritating. All made positive comments on the use of repetition in lessons with five stating that this helps learning or “makes the information stick”. One student thought that repetition in class may result in less need to study hard out of class. Three students commented that repetition was not irritating although the remainder did not comment. In reply to the question “do the pauses in the lessons have a positive impact on learning”, all replied positively. Seven answers expressed something to the effect of “they don’t get so tired as a result of the pauses”. One student replied that it was fun to play with clay. While this answer may be viewed as not serious, it is important to remember that an enjoyable experience in the classroom may contribute to better learning. All students gave positive answers to the question; do you want to see more "spaced learning" used in the future? Justify your answers. Six students commented that the technique should be used in some but not all lessons and that they did not think that it was suitable for all subjects and did not want to see it totally replace conventional teaching methods. The students were asked to give general comments about spaced learning in order to freely express any relevant ideas that had not been covered elsewhere in the survey. Five students gave comments about spaced learning and were positive in nature. One student commented that it was fun and something different, another student thought that there shouldn’t be too much information but otherwise it was good. This suggests that the lessons were thought to be too intensive. In summary the survey indicates that the class is very positive to spaced learning with a variety of favorable comments being made.

4.3.4 Summary of the teacher interview.

The teacher interviewed was responsible for teaching both the biology and chemistry courses for the class in question and has a research background in molecular biology. We initially

discussed the neuroscience behind spaced learning and the practical aspects of applying it. As the technique is proposed to enhance long-term memory, we discussed whether spaced learning can help memory. While it was not possible to know what was happening at a cellular level, *it generally helps to repeat limited amounts of information to aid memorization. So yes it certainly makes sense to have a teaching technique where repetition is planned. Intuitively, spaced learning should help memorisation.* Can spaced learning aid understanding? *It is easier to understand something after it has been heard before resulting in a level of background knowledge. It therefore seems intuitive that spaced learning can help the learning process. It is important and necessary to have a good command of ground concepts as a basis for understanding. Factual knowledge is a prerequisite for understanding.* You have given a spaced learning lesson, what are your reflections. *Spontaneously, I thought that it worked well. The students thought it was "cool". It appeared to work as well as conventional teaching but with the novelty of being a little different. It was hard to judge if it gave any advantage over conventional teaching.* One thing that I observed was that the class was far more responsive to your questions in the second teaching session of the lesson as compared to mine. Do you think it is important to have a teacher known to the class when using this form of teaching? *It can only help to have a teacher who is known and trusted by the class, when a high degree of interaction is needed. This class is particularly quiet and so having a teacher that they feel comfortable with, is particularly important.* How would you see spaced learning being used in teaching? *I could see it being used to introduce new material. I could imagine that it would be particularly useful for revision, especially before a final examination where large amounts a material would need to be covered in a short period of time.* What sort of activities would you like to see used in the gaps? *The gaps felt somewhat artificial. If an alternative activity to the lesson is needed, then drawing specimens observed under microscopes, could be tried. The gaps could then have a constructive function.* Is it

possible to design classroom teaching on the basis of neuroscience findings? *It may not be possible to extrapolate from laboratory experiments to the classroom. In the case of spaced learning, the method intuitively fits the observations. Here, it may be better to refine the method by directly studying memory in the classroom and returning to the laboratory to explain the findings.* Have you any general comments to make. *It appears to be a good thing. It is an interesting technique and could be used occasionally to compliment other teaching methods. It can't however, replace conventional teaching.* Would you consider using spaced learning in the future? *Yes, definitely. It could provide an interesting variation in how to present lessons.*

5. Discussion.

5.1 Swedish school study.

Having read reports from England claiming sensational exam results following spaced learning lessons, it was interesting to see if these could be repeated. The discussion will focus on what was learned about constructing spaced learning lessons, if they worked well and finally, what could be improved should such a study be attempted again.

There are no hard rules about how to construct a spaced learning class other than the time frame for repetition. As a guideline, a video of a spaced learning lesson given in an English high school is available on-line (found in Bradley & Patton 2012). I have also experienced two spaced learning classes in England. One was part of a workshop in an educational conference (Gittner & Kelley 2012) and the second a visit to a high school and involved teaching a class of 14-15 year olds. The lessons were delivered at a relatively high tempo but without giving a feeling of being stressed. Ideas and explanations were certainly presented in the lessons but much of the emphasis was put on factual content and labelling the components of systems. The current study examined teaching older students (17-18 years) and

consequently involved using more advanced material. The emphasis of these lessons was on function, although it became clear that a lot of terminology had to be introduced and it was difficult not to include too much material. A PowerPoint presentation with animation provided an effective way to present the lesson material. The PowerPoint presentation also provided a framework for a question sheet that was used in the third teaching period of the lesson. The questions were mostly concerning function. The presentation worked although teaching under a rigid time constraint felt stressful.

It was difficult to assess how well the lessons worked. Testing was performed without forewarning and no demands were made to prepare or revise. The method of testing, which consisted of short written answers was aimed to test both memory and understanding directly from the lesson. On reflection, it was naïve to omit any exercises or give clear instructions for test preparation which could have led to memory consolidation processes. The first diagnostic test results from all three lessons showed a marked improvement over the pre-test indicating that the spaced learning technique had worked to some degree. The first diagnostic test for cell function and immune defences were answered reasonably well, while the lipid test was disappointing. Possibly this indicated that too much detailed information was presented in this lesson. When the first and second diagnostic tests for the cell function lesson were compared, the decrease seen may indicate that further steps are needed to consolidate what was learned. No further teaching, exercises or forewarning for the test was given between the first and second diagnostic tests and the decrease in test performance may reflect forgetting of factual matter. The second lipid diagnostic test followed both conventional teaching and a class examination. Despite this only a marginal improvement was seen in the in the results of the second diagnostic test over that of the first. The class appeared weak in general organic chemistry or had surprisingly little background and on reflection this was not the ideal choice of topic for spaced learning.

A more rigorous study of spaced learning would require close collaboration with schools. Firstly, selection of suitable classes is needed as a rigorous study would require parallel classes in order to perform controlled studies. Larger schools may provide parallel classes in many subjects. In the case of smaller schools, the choice of subject may be important and *naturkunskap* may provide a good option as it is common to many programmes. Observations from the current study suggest that it is important to have teaching performed by the teacher normally involved in the course. This is both to ensure confident interaction within the class and to have an accurate appraisal of the background and progress when designing spaced learning lessons. Further improvements to the spaced learning studies performed in England are discussed below.

5.2 Spaced learning studies conducted in English schools.

A number of studies aimed at appraising spaced learning have been reported from schools in England. Studies have used scenarios where spaced learning has been applied as the only method of instruction prior to testing or it has been incorporated into teaching programmes and tested under controlled conditions. The method of testing, namely multiple-choice papers taken from previous nationally set examinations, gives the advantage of well formulated questions and unambiguous answers for objective comparison. Kelley and Whatson (2013) have reported that similar exam scores have been obtained when comparing students who have taken a four month biology module with a cohort that only received sixty minutes of spaced learning covering the same module. Furthermore in a second study, they report that students recorded a better performance in exams (7.6% higher mean scores) having used a spaced learning lesson as revision following courses in physics and biology, when compared to a control group who received revision by conventional teaching methods. It is argued that the results demonstrate a very rapid and efficient method of creating long-term memory. Furthermore this was demonstrated using material from English national curriculum biology.

Similar results from preliminary trials have been presented by Kelley (2008). An important question is whether complex learning and deeper understanding can be enhanced by spaced learning. If spaced learning can provide a solid basis of factual matter and basic concepts, then presumably this can only aid understanding. Some teachers in England are attempting to condense parts of courses using spaced learning in order to win time for using teaching methods aimed at promoting better understanding (Bradley & Patton 2012). Kelley and Whatson (2013) do not argue that increased understanding is demonstrated from their recently published study. They point out the need for alternative methods of testing to be investigated. Multiple-choice testing has been criticised for not measuring complex learning well (Frederiksen 1984) and that by exposing the correct answer, that they may aid retrieval processes. The later point may lead to falsely high scores being returned.

Clearly, further studies need to be performed. Spaced learning lessons have been constructed and used on students up to eighteen years old. However, Kelley's tests have been performed on students between the ages of thirteen and fifteen and clearly there is a need for other age groups to be tested. Different scenarios of integrating spaced learning with other teaching methods need to be investigated. The spaced learning temporal schedule of three teaching periods separated by two ten minute gaps is based on Fields' (2005) original observations from experiments using rat tissue. It would be interesting to vary timing in order to determine if it is optimal or if timing is in fact critical. Kelley reported a case were a mock biology exam was taken by a class after receiving spaced learning as the sole method of instruction. The same class took a similar test one year later after a full course of conventional teaching. Surprisingly, the higher test scores were found in the first test. This is inconsistent with spaced learning having a long term effect having a long term effect on memory. It would be interesting to compare different approaches to testing in order to assess what had been learned. It may then be possible to determine the contribution of spaced learning to factual

content or terminology and descriptive or theoretical understanding. Kelley and colleagues have used spaced learning for various subjects (Bradley & Patton 2012) and this will be discussed below. The reported testing has been based on teaching biology or other science subjects. It would be very interesting to see if measurable benefits could be shown when applying spaced learning to other subjects.

5.3 General discussion.

So does spaced learning really work? Alastair Gittner is head of science in an English secondary school and routinely uses spaced learning for revision purposes to prepare students for exams and believes the method is very beneficial in that context, but points out that it is "not an alternative to good teaching rather is another learning tool that is proving successful" (Gittner 2010). In a personal communication, Gittner described revision classes using spaced learning that were organised outside of normal school hours. These classes were not obligatory but were very well attended, suggesting that spaced learning is popular with students. Controlled experiments provide evidence for improved exam results when using spaced learning for revision (Kelley & Whatson 2013). Furthermore, using spaced learning, it is possible to cover large amounts of course material quickly. Taken together, a strong case is presented for spaced learning being a good tool for revision. Attempts have been made to use spaced learning in early stages of courses in order to efficiently introduce relevant factual material and basic concepts. By doing so, it is hoped that more time can be spent on forms of inquiry based learning. Evidence is still needed to support if spaced learning can be used in this way. It would be interesting to know whether spaced learning works for all students. While the question has not been properly investigated, a number of observations suggest that students with attention difficulties find the lessons helpful. It is speculated that the intense nature of the presentation may in fact help in holding students attention. Students with a dyslexic profile benefit from them as the lessons are very visual and involve the minimum of

writing. Spaced learning has been used for different subjects although it is still unclear whether the technique is equally applicable to all subjects. Examples of spaced learning lessons (PowerPoint presentations) can be found for subjects including English, mathematics, history, psychology, art (theory), human biology and Spanish (Bradley & Patton 2012). Paul Kelley is a strong proponent of spaced learning being applicable to any subject (Marley 2009). In principle, any type of subject matter that requires a significant memory component could be helped by spaced learning. This does not necessarily have to be limited to learning raw facts, but can involve theoretical arguments, historical scenarios, styles in art (with visual components) and conceptual models, to name some examples. It is not clear that spaced learning would make a positive contribution to teaching mathematics. School level mathematics involves problem solving and application rather than reliance upon memorization of presented material. Both pupils and teachers have questioned the value of using spaced learning with mathematics (Bradley & Patton 2012). In the current study, presenting chemical structures using spaced learning during the lipid lesson worked poorly. Detailed information at this level of education may be unsuitable to be presented using spaced learning. The descriptive areas of the two biology lessons appeared to be understood and recalled but terminology rich areas were still problematic and raises the question of how applicable spaced learning is for gymnasium level education. It is important to remember that Kelley's study was performed with younger students and presumably less demanding material, when comparing to the current study.

5.4 The value of neuroeducation.

The field of neuroeducation attempts to find links between neuroscience and education with the eventual aim of designing appropriate learning environments (Ansari, De Smedt & Grabner 2012). A lot of attention has been given to addressing specific learning difficulties such as dyslexia, dyscalculia and ADHD. Neuroimaging techniques have contributed greatly

to understanding the underlying mechanisms involved in reading and when used in combination with performance tests has helped to develop strategies for the benefit of dyslexics (Richlan, Kronbichler & Wimmer 2009). The spaced learning teaching technique is extrapolated from neuroscience experiments to investigate the cellular mechanisms of long-term memory formation. The technique is designed to be generally applicable as it is not based on a handicap but rather a general mechanism for long-term memory formation. Interestingly, spaced learning's creator, Paul Kelley, also examines the role of circadian cycles for education. Rigorous testing has shown that teenagers perform better in school later in the day. Kelley consequently scheduled his sixth form students to start no earlier than ten o'clock.

5.5 Concluding remarks.

In summary, spaced learning can be seen as a brave initiative to develop a teaching technique directly from neuroscience research. When the technique gained public attention in 2006, as a new and radically different approach to teaching, it became the subject of much controversy. Many people were excited about the possibility of a technique that could lead to more efficient education. Critics were concerned that it just taught facts, that students were playing in class or that the unconventional nature of the method was unacceptable to the more conservative minded. Today, spaced learning is gaining popularity in English schools and training courses are being organised. It has gained popularity as a tool for revision with both students and teachers alike. While trials are being made in using spaced learning to introduce material in the earlier stages of a course, it is still unclear as to how effective this is and many questions remain to be answered. The results from the current study support using spaced learning as a revision tool. Information can be presented intensively and the test results indicate a good performance soon after the lesson. This is consistent with results presented in England. The case for using the technique in an introduction to courses is not supported from

the current study. Major questions can be raised about the type of content that can be taught using spaced learning at *gymnasium* level in Sweden. My own experience is that introducing material with a high degree of detailed knowledge such as terminology or chemical structures is not suitable for spaced learning.

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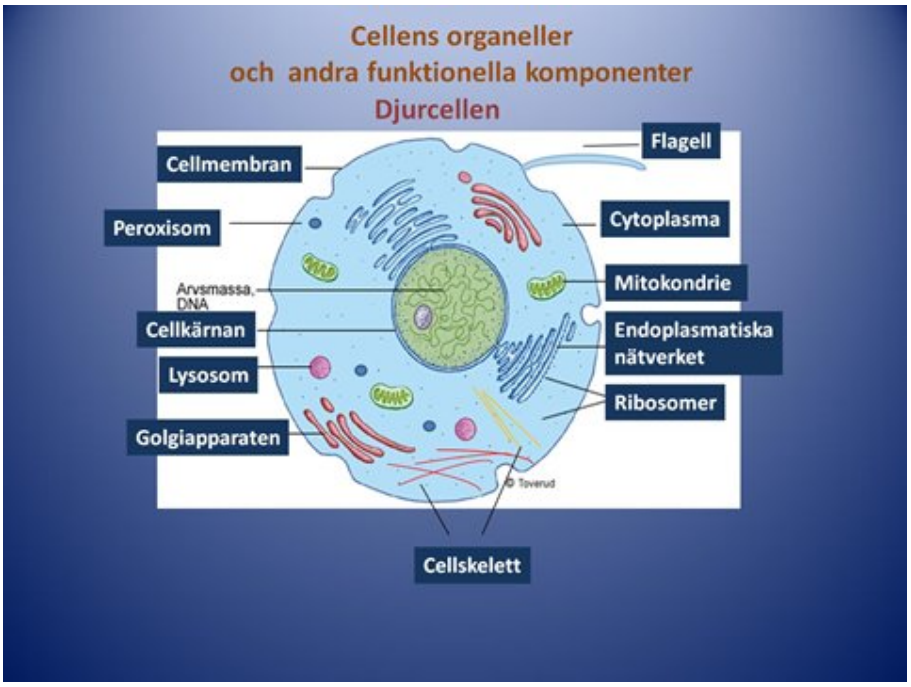
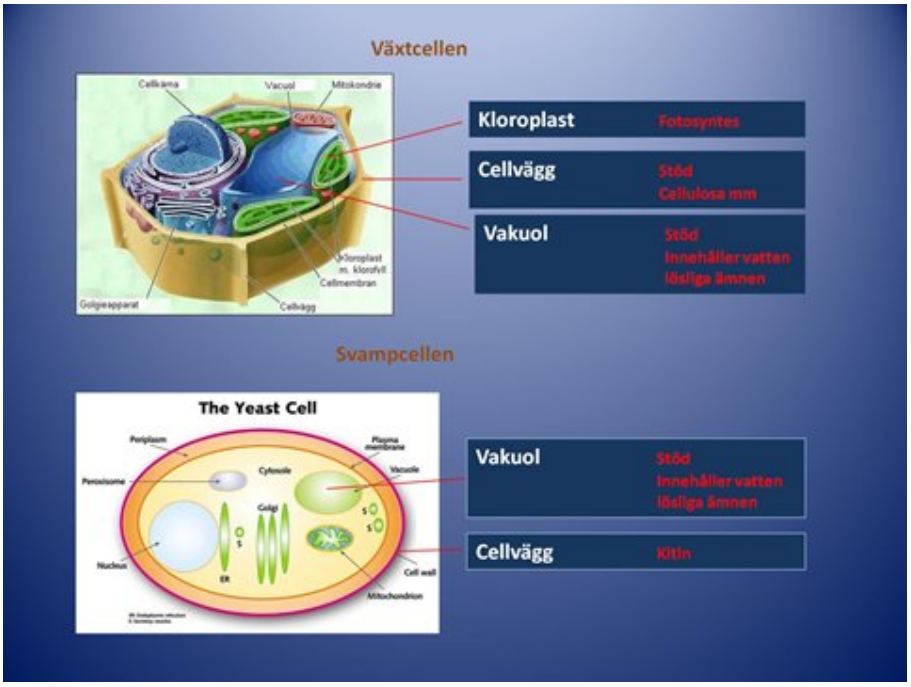
Appendix 1. Presentation slides for Cell Function and Organelles lesson.





Cellkärnan

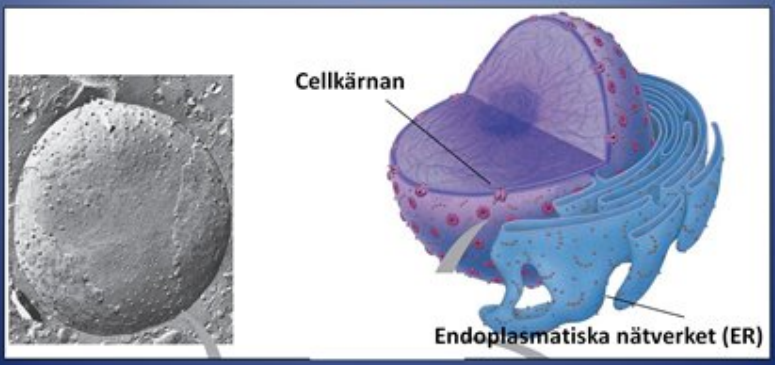
Innehåller DNA, Kromosomer

Dubbel-membran

DNA transkriberas till RNA

Porer – Transport (mRNA)

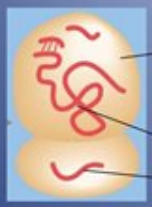
Sammanbundet med endoplasmatiska nätverket.



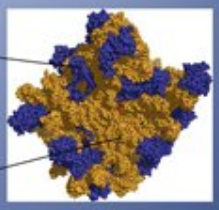
Ribosomer

Makromolekylär struktur består av RNA och proteiner

Inget membran

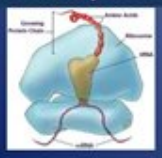


Proteiner



RNA

Proteinsyntes

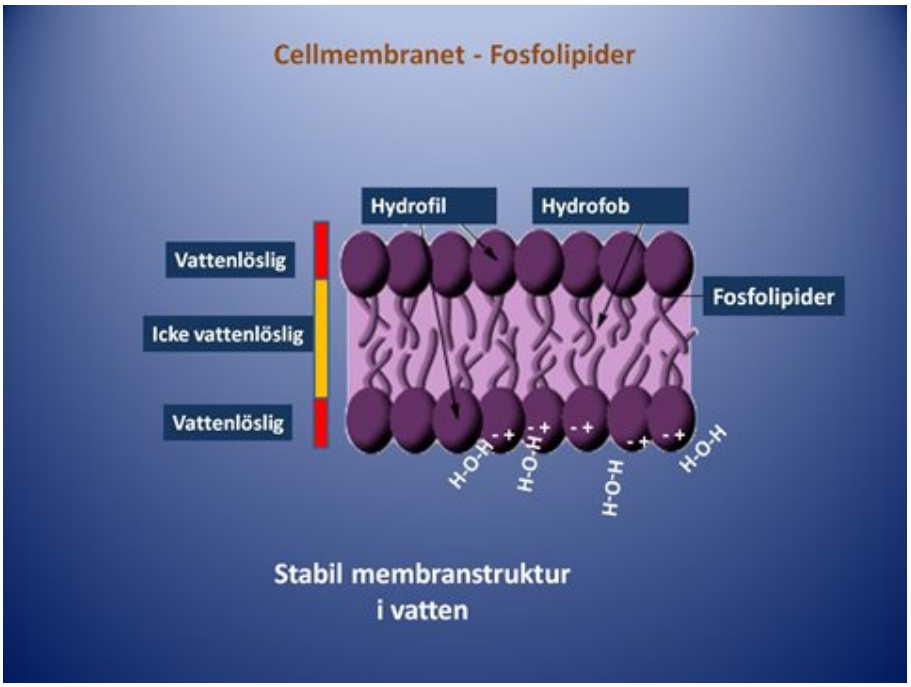


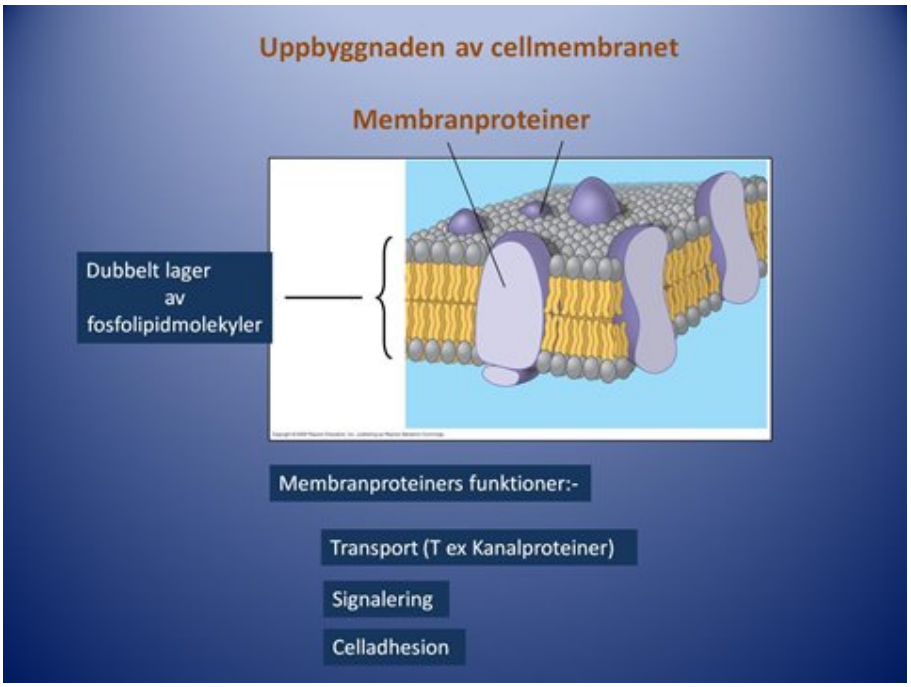
Fria Ribosomer

Proteiner i cytoplasman

Membran-bundna ribosomer

Proteiner till cellens utsida

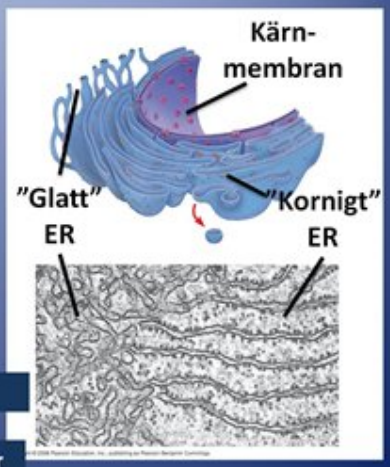

Cellmembranet - Fosfolipider
Hydrofil
Hydrofob
Vattenlöslig
Icke vattenlöslig
Vattenlöslig
Fosfolipider
H-O-H
H-O-H
H-O-H
H-O-H
Stabil membranstruktur
i vatten


Uppbyggnaden av cellmembranet
Membranproteiner
Dubbelt lager
av
fosfolipidmolekyler
Membranproteiners funktioner:-
Transport (T ex Kanalproteiner)
Signalering
Celladhesion

Endoplasmatiska nätverket (ER)

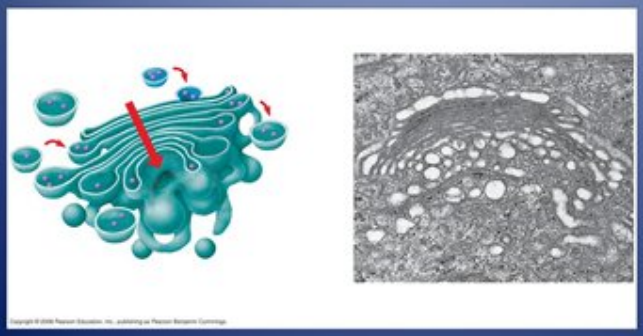
- Membranös struktur
- Tar upp en stor del av cytoplasman
- Två system

Glatta Endoplasmatiska nätverket	Korniga Endoplasmatiska nätverket
Lipidsyntes	Proteinsyntes
Avgiftning	Proteintransport
	Proteinmodifieringar



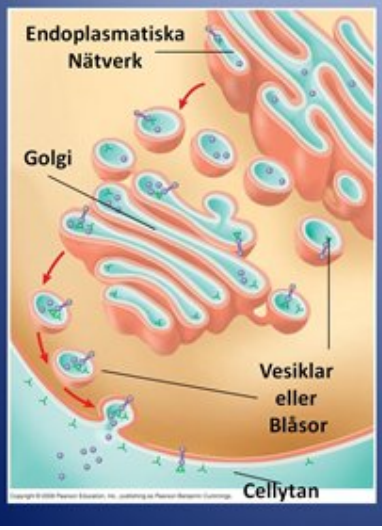
Golgiapparaten

- Membransäckar
- Transport till cellytan
- Proteinmodifieringar



Protein utsöndring/sekretion

Vägen till cellytan



Endoplasmatiska Nätverket

↓

Vesiklar (Blåsor)

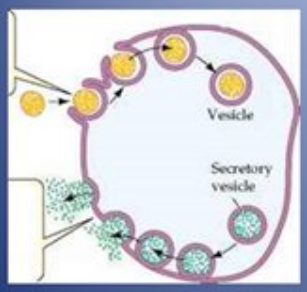
Golgiapparatan

↓

Vesiklar (Blåsor)

Cellmembranet eller utsöndrad från cellen

Endocytos – Exocytos
(ex på transport med hjälp av vesiklar)

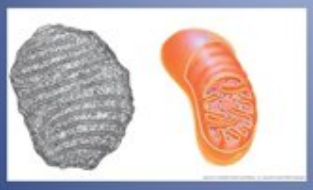


Endocytos

Exocytos

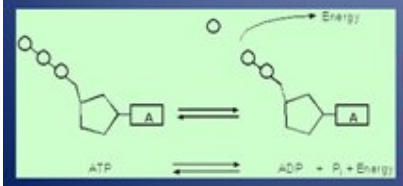
Energiomvandling

Mitokondrien
(Alla eukaryota celler)



Kloroplasten

Cellandning - Bildning av ATP



Fotosyntes - Glukos

Lagring av stärkelse

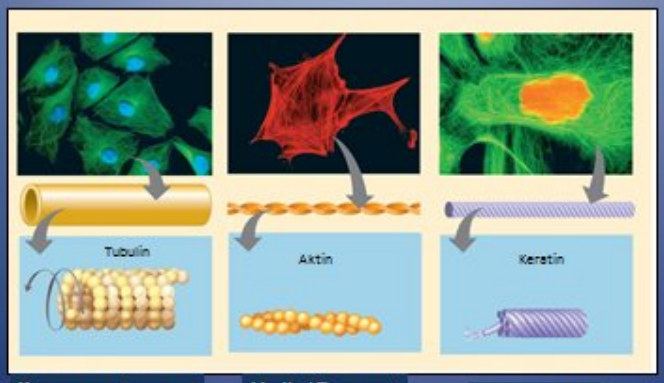
Gemensam

- Dubbelt membran
- Eget DNA och Ribosomer
- Prokaryot ursprung?

Cellskelettet

Funktion	Struktur och stöd	Cellrörelse	Organell Transport

Mikrotubuli



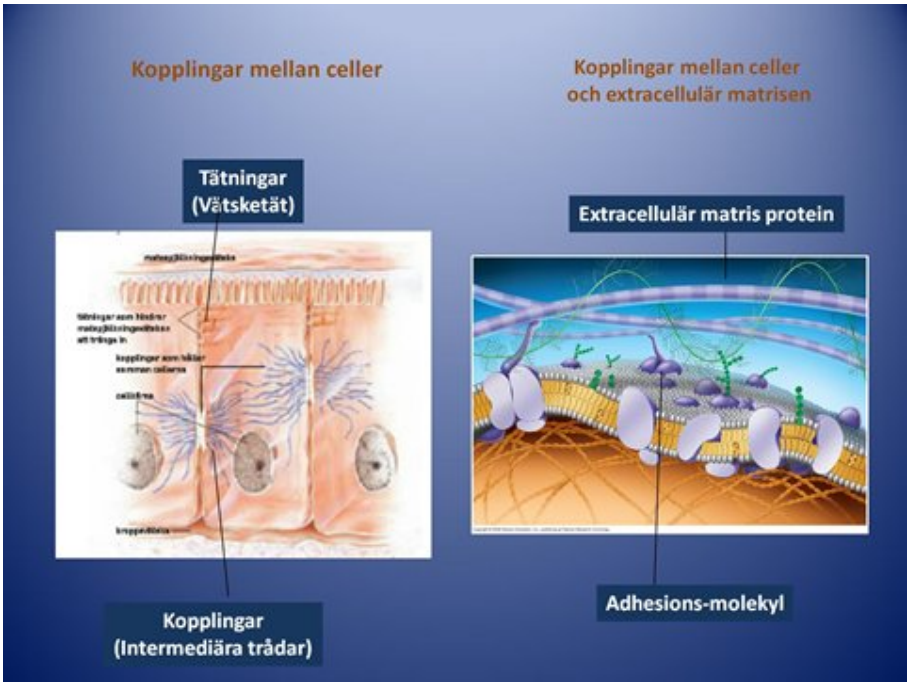
- Kromosom transport
- Motor Proteiner
- Del av flimmerhår

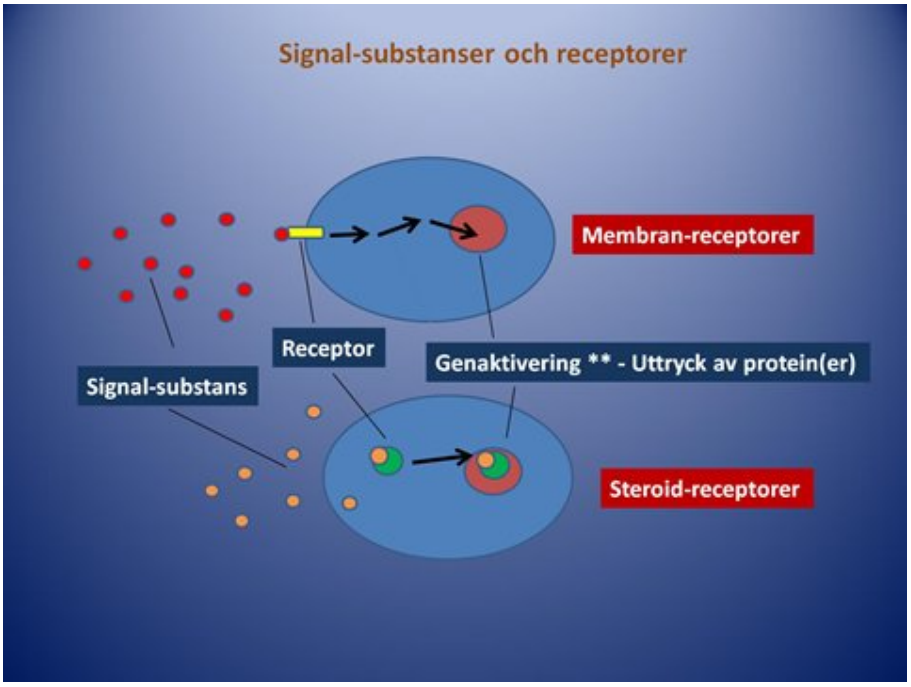
Aktintrådar

- Vesikel Transport
- Motor Proteiner
- Celldelning

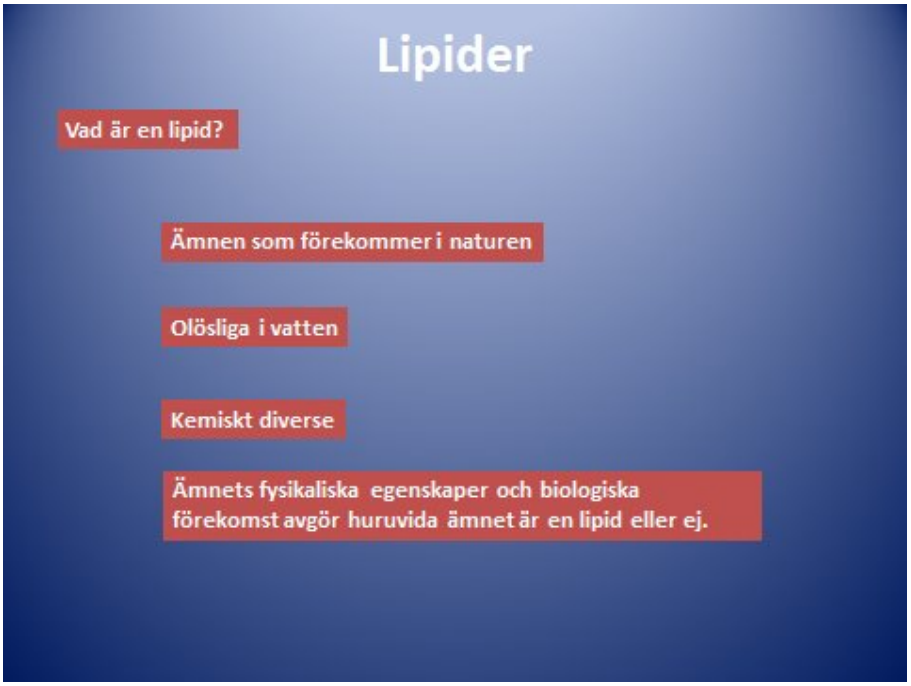
Intermediära Trådar

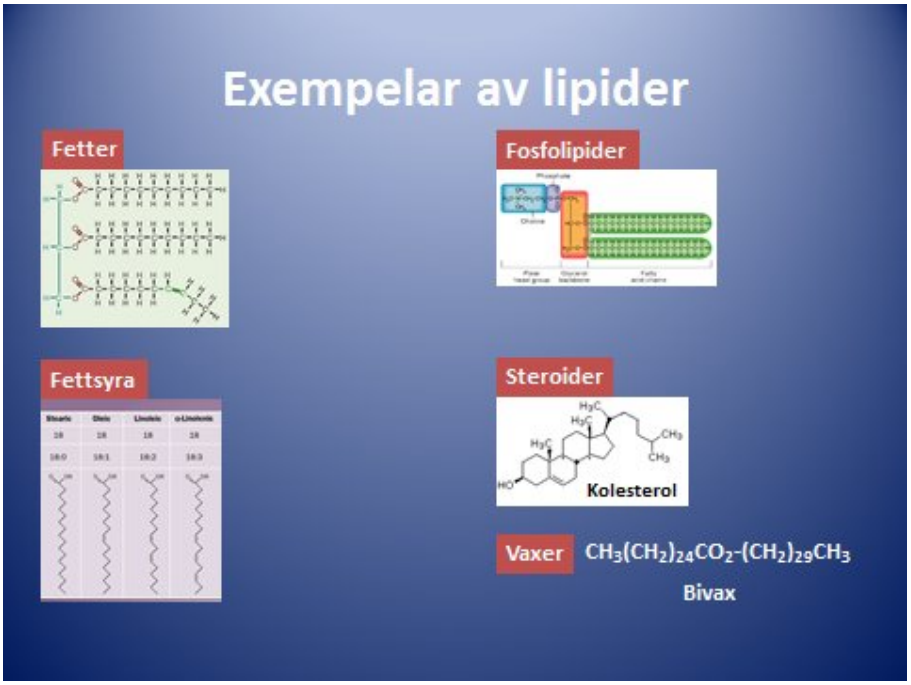
- Förstärkning


Kopplingar mellan celler
Kopplingar mellan celler och extracellulär matrisen
Tätningar (Vätsketät)
Extracellulär matris protein
Kopplingar (Intermediära trådar)
Adhesions-molekyl

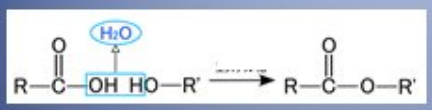

Signal-substanser och receptorer
Membran-receptorer
Receptor
Genaktivering ** - Uttryck av protein(er)
Signal-substans
Steroid-receptorer

Appendix 2. Presentation slides for Lipids lesson.





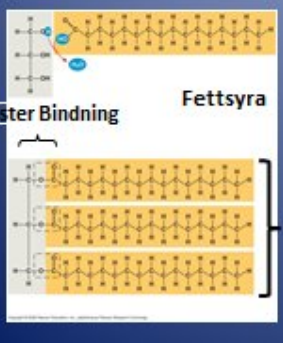
Fetter - Uppbyggnad



Kondensation

Syra | Alkohol | Ester

Glycerol



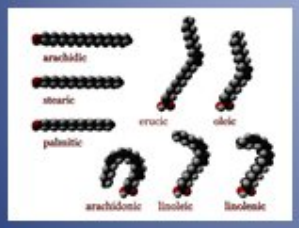
Fettsyra

Ester Bindning

Fettmolekyl

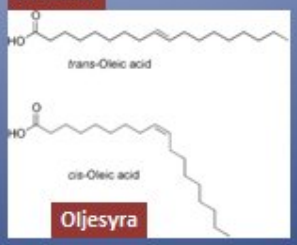
Fettsyror

Exempelar



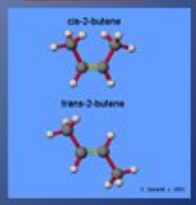
Palmitinsyra - Mättat

Omättat

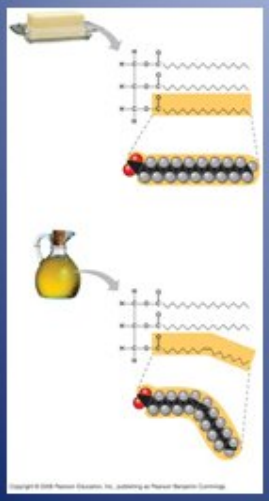


Oljesyra

Cis / Trans ställning



Mättade och omättade fetter

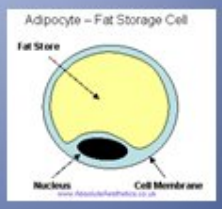


Stearinsyra (mättade)

Oljesyra (omättade)

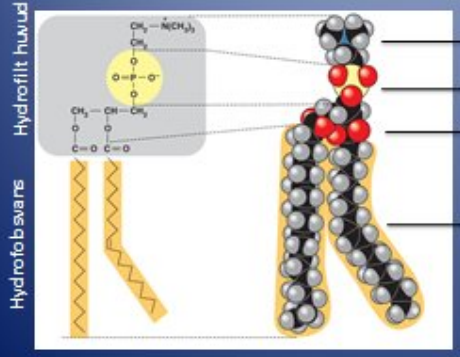
Funktioner av fetter

- Energi
- Isolering
- Stötdampning
- Fett löslig ämnar

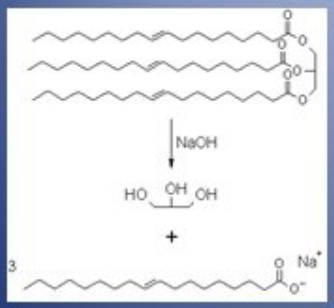


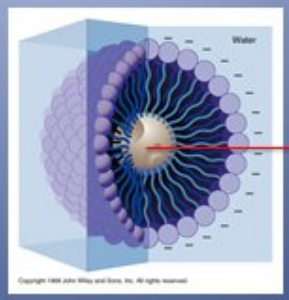
- Övervigt – allt vanliga problem (49% övervikt enligt Folkhälsoinstitutet)

Fosfolipider



Förtvålning av fett



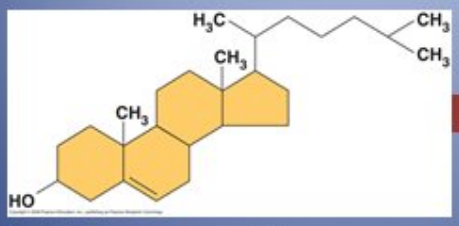


Smuts

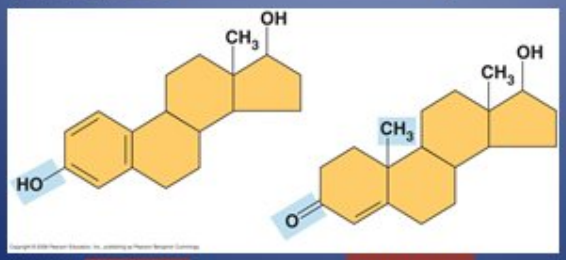
(olösligt i vatten)

Micell

Steroider



Kolesterol



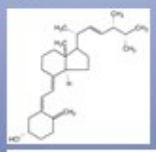
Östradiol

Testosteron

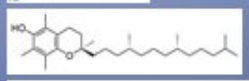
Fettlösliga vitaminer

Retinol (form av vitamin A)

Vitamin D_2



Vitamin E



Vitamin K (K_1)

Essentiella fettsyror

Omega-3 fettsyror

alpha-linolenic acid (ALA)

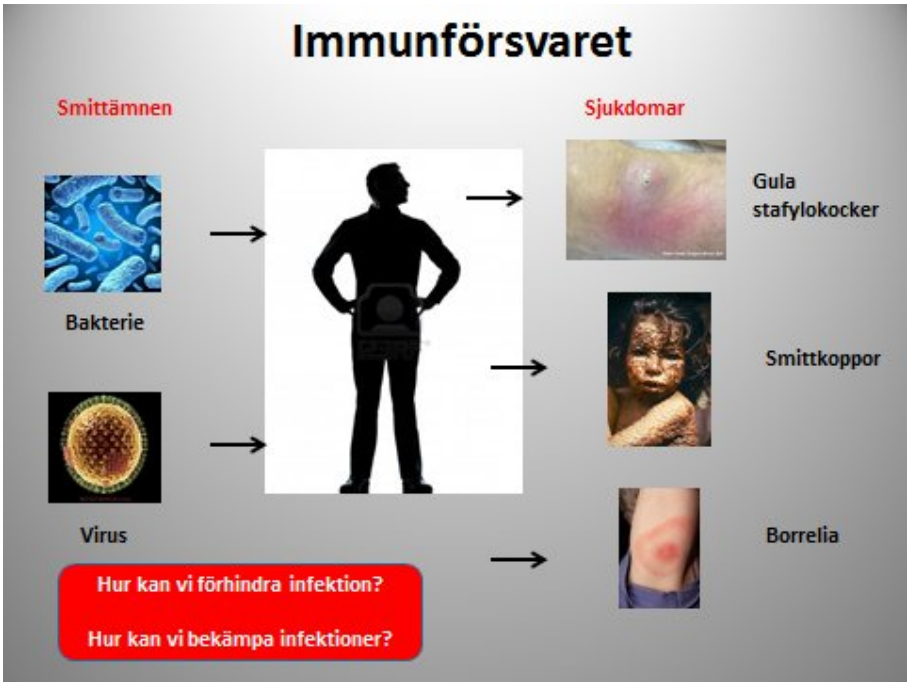
eicosapentaenoic acid (EPA).

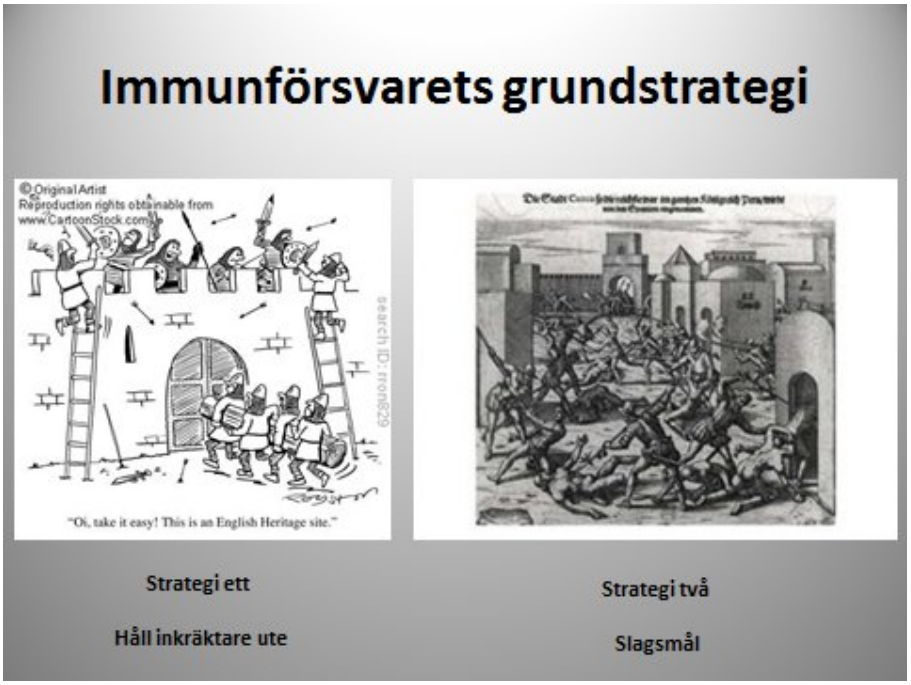
docosahexaenoic acid (DHA)

Omega-6 fettsyra

linoleic acid (LA)

Appendix 3. Presentation slides for Immune Defence lesson.





Immunförsvaret

Medfödda

Allmänt försvar
Snabbt respons

Exempel

Hud

Lerigt ansikte - inget problem

Infekterade sår

Fagocyter

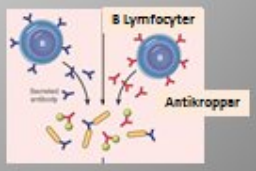
Granulocyt slukar gonorré celler

Adaptiva

Respons är anpassad till specifika sjukdomar
Långsam respons
Immunsystemet kan "komma ihåg" en sjukdom. Om samma sjukdom påträffas igen, kommer individen att ha skydd.

Exempel

B-lymfocyters försvar



B-lymfocyter producerar antikroppar mot patogener

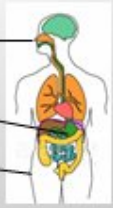
Medfödda Försvaret

Barriärer

Slemhinnor

Magsyra

Hud



Cellförsvar

Makrofager

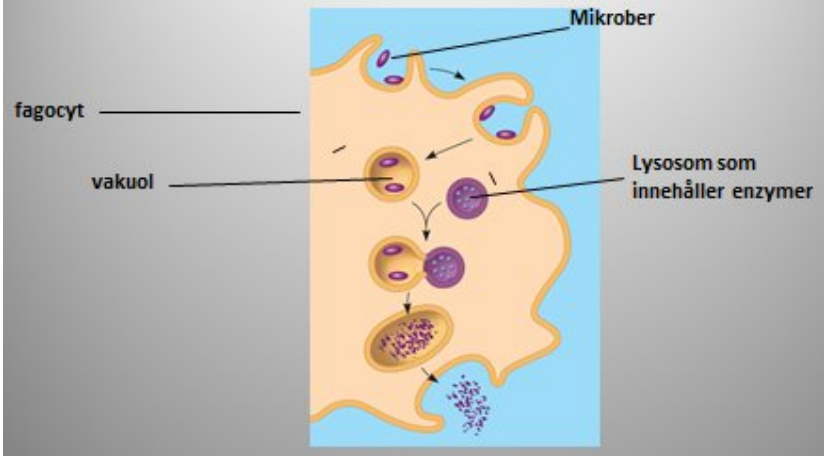
Granulocyter

NK-celler (Natural Killer)

Fagocytos

Svepelektronmikroskopi (färglagda bilder)

Fagocytos



Medfödda Försvaret

Inflammation

Kännetecken: -

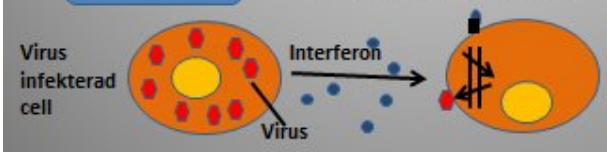
Huden bli röd och svullen

Feber

Under huden: -
Frisättning av inflammatoriska faktorer
Blodkärlen vidgas
Vita blodkroppar (leukocyter) migrerar till inflammationsområdet

Interferon

Interferon (signalsubstans) frisläpps av virusinfekterade celler.
Utlöser försvarsmekanismer som förhindrar virusinfektion.



Adaptiva Immunförsvaret

Lymfocyter

Transmissions-elektronmikroskopi

Lymfocyter är vita blodkroppar
Det finns olika typer av lymfocyter
Dessa ser liknande ut vid användning av ljusmikroskopi
Har olika funktioner och uttrycker olika proteiner på cellytan

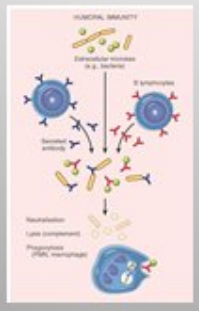
B-lymfocyter (B-celler)
Producera antikroppar

T-lymfocyter (T-celler)
T-hjälparceller
Bidra till antikropps försvar
Cytotoxiska T-celler
Döda infekterad celler

Adaptiva Immunförsvaret

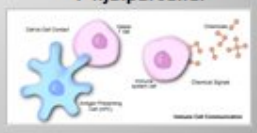
Aktiva

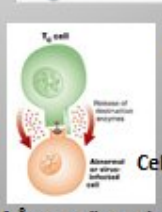
B-lymfocyter
Producerar antikroppar som binder antigener som finns utanför celler



T-lymfocyter
Upptäcker antigener som finns inuti celler (T.ex virus)

T-hjälparceller





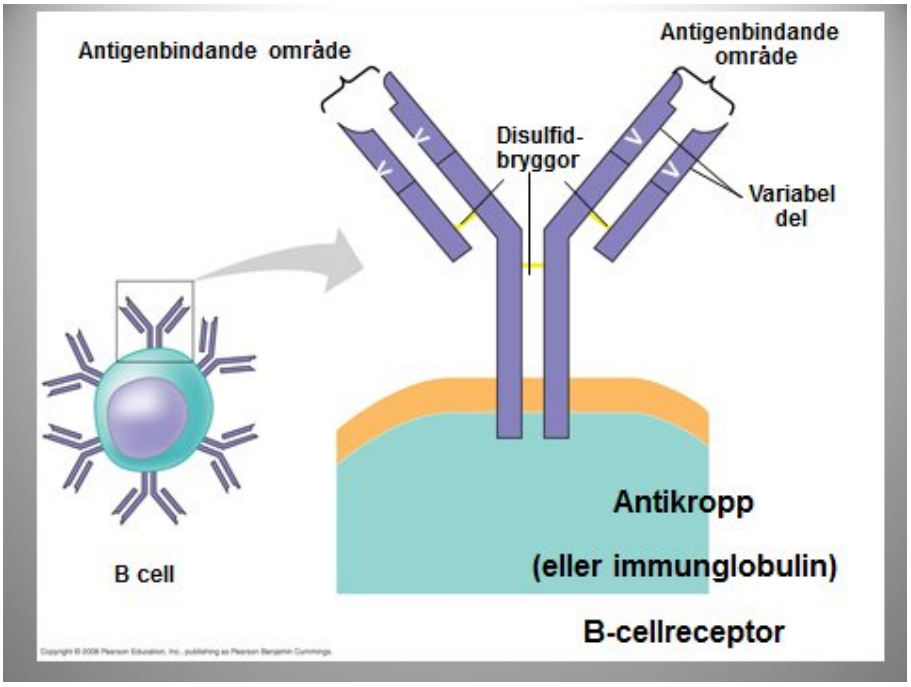
Cytotoxiska T-celler

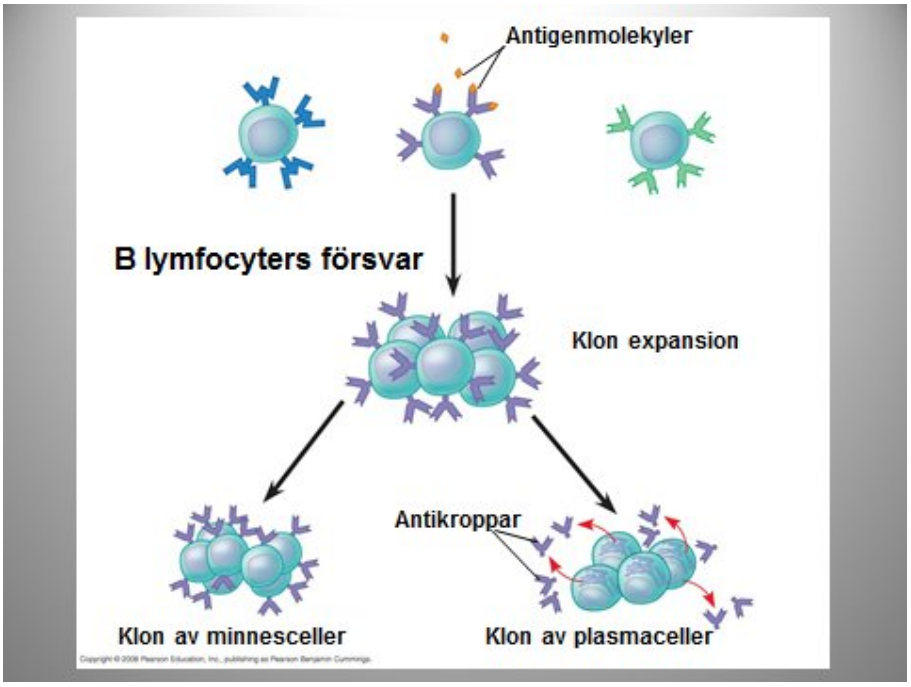
Cellen dör!

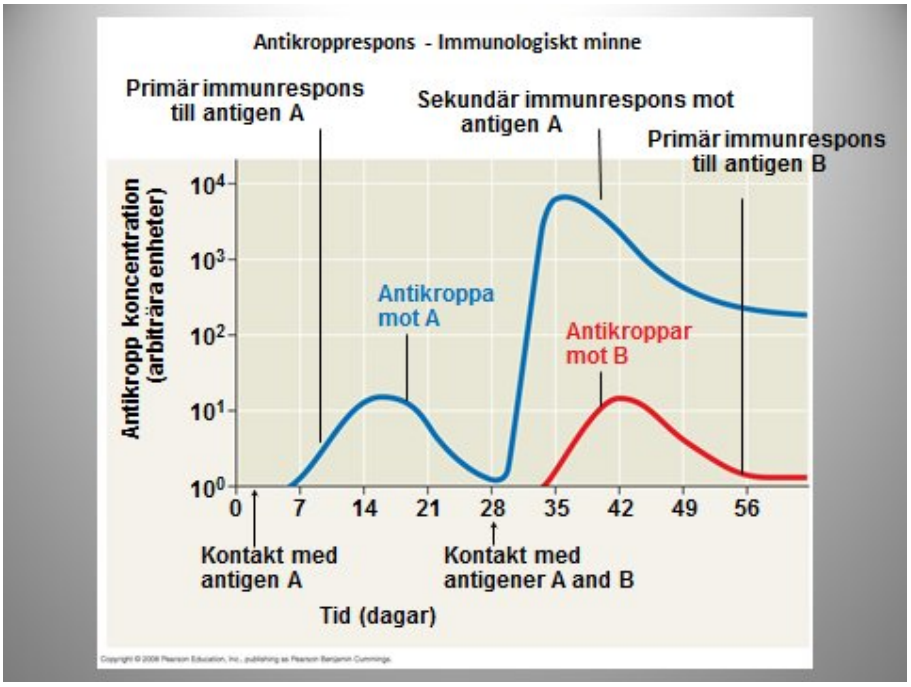
Antigen - är ett ämne som framkallar en reaktion som leder till nybildning av antikroppar.

Passiva

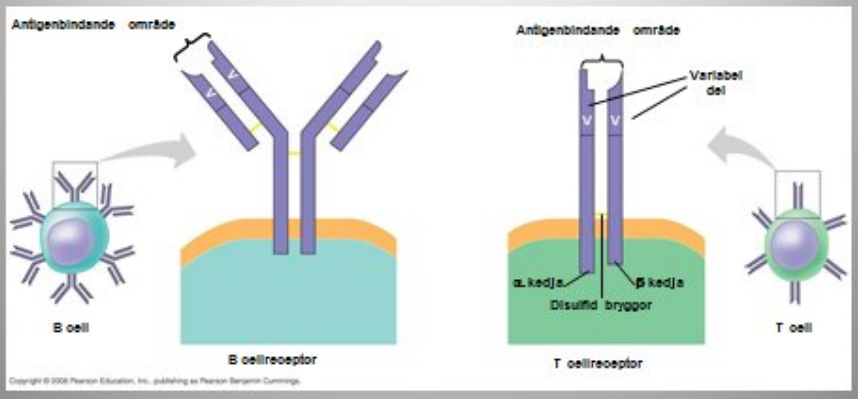
Antikroppar som överförs från mor över placenta
Antikroppar som överförs från mor via mjölk
Antikroppar kan ges som behandling


Antigenbindande område
Antigenbindande område
Disulfid-bryggor
Variabel del
B cell
Antikropp
(eller immunglobulin)
B-cellreceptor

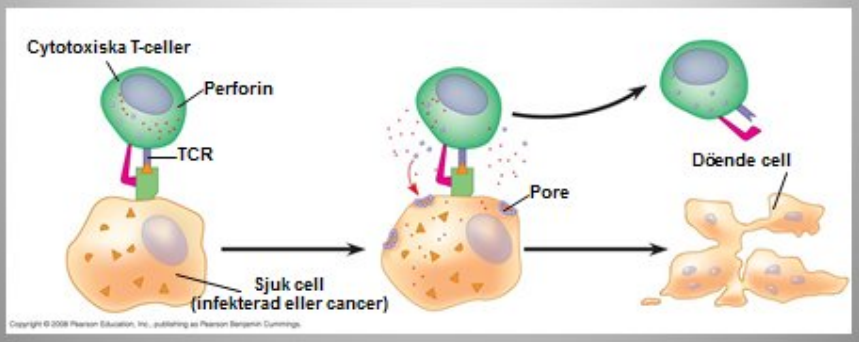

Antigenmolekyler
B lymfocyters försvar
Klon expansion
Antikroppar
Klon av minnesceller
Klon av plasmaceller



T-lymfocyter och T-cellreceptorn

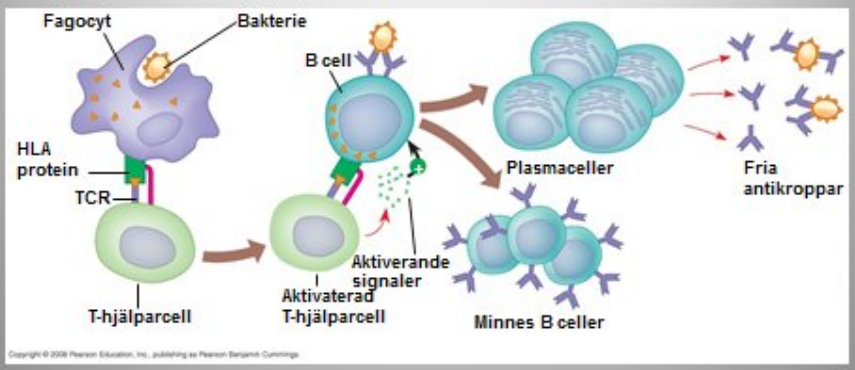


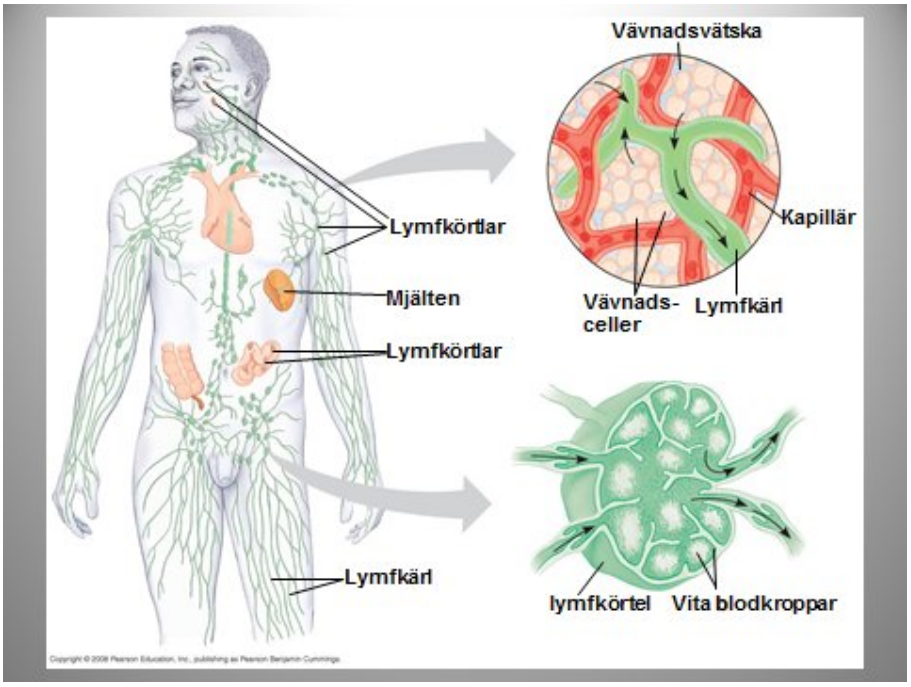
Cytotoxiska T-celler döda sjuka celler



T-hjälparceller

ge signaler för att aktivera B-celler (och T-celler)




Lymfkörtlar
Mjälten
Lymfkörtlar
Lymfkärl
Vävnadsvätska
Kapillär
Vävnads-
celler
Lymfkärl
lymfkörtel
Vita blodkroppar

Appendix 4. Diagnostic test questions – Cell Function.

Diagnostiskt Test - Celler.

1. Vad är en cell?

2. Har alla levande organismer celler?

3. Vad är en organell?

4. Vad är mitokondrier? Vilken funktion har dom?

5. Vad är en lysosom? Vilken funktion har den?

6. Innehåller djur-, växt- och svampceller kärnor?

7. Innehåller alla celler vakuoler?

8. Vilka är funktionerna hos det endoplasmatiska nätverket?

9. Hur kommunicerar celler med varandra?

10. Vad är en vesikel? Vad gör den?

11. Vilka organeller omges av ett enkelt membran?

12. Vilka organeller omges av två separata membran?

13. Vad är ursprunget till mitokondrier och kloroplaster?

Appendix 5. Diagnostic test questions – Lipids.

Diagnostiskt Test – Lipider.

1. Vad är lipider?

2. Vad består fetter av?

3. Vad består fosfolipider av?

4. Varför är oljor flytande vid rumstemperatur?

5. Vilken fysiologisk funktion har fett?

6. Nämn tre komponenter i cellmembran.

7. Vilka är deras funktioner?

8. Vad är den kemiska sammansättningen av tvål?

9. Hur är den tillverkad?

10. Rita en micell.

11. Hur löser miceller upp lipider i vatten?

12. Namn en funktion av en steroidförening.

13. Vilka klasser av fettlösliga föreningar kan kroppen inte syntetisera själva?

Appendix 6. Diagnostic test questions – Immune defence.

Diagnostiskt test.

Hur förhindrar vi smittämnen från att komma in i kroppen?

Hur bekämpar fagocyter infektion?

Vilken roll har lysosomer i fagocytos?

Vilka är kännetecknen för inflammation?

B-och T-lymfocyter detekterar antigener på olika sätt, beskriv dessa.

Ge ett exempel på hur minnet fungerar i immunsystemet.

Vilka celler producerar antikroppar?

Vad är funktionen av lymfkärlen.

Appendix 7. Survey questions.

Vad är din åsikt om ”spaced learning”?

”Spaced learning” är en undervisningsmetod där innehållet upprepas inom lektionerna och är utformad för att göra det lättare att komma ihåg innehållet och därmed underlätta inlärningen.

Ange din ställning till följande påståenden:

	Instämmer fullständigt	Instämmer	Osäker	Håller inte med	Håller inte alls med
1. Spaced learning är en bra metod för att införa nya begrepp.					
2. Spaced Learning hjälper att ge bättre förståelse för det som lärs ut.					
3. Spaced learning är ett bra sätt att repetera inför ett prov.					
4. Spaced learning fungerar bra för att komplettera andra undervisningsmetoder.					
5. Spaced learning lektionerna var för intensiva och svåra att följa.					

Svara på följande frågor med egna ord:

6. Berätta vad du förstår om undervisningstekniken ”spaced learning”.

7. Tycker du att ”spaced learning” hjälper dig komma ihåg det som lärdes ut?

8. Har metoden hjälpt dig förstå hur biologiska system fungerar?

9. Vad tycker du om upprepning av information i lektioner? Hjälper det vid inlärning? Är det irriterande att ha begrepp presenterade upprepade gånger?

10. Har pauserna i lektionerna haft en positiv effekt på inlärningen?

11. Vill du se mer ”spaced learning” användas i framtiden? Motivera.

12. Har du några allmänna kommentarer om ”spaced learning”?