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## Keeping common knowledge floating

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2008

[Link to publication](#)

*Citation for published version (APA):*

Wadsö, L. (2008). *Keeping common knowledge floating*. (Report TVBM (Intern 7000-rapport); Vol. 7196). Division of Building Materials, LTH, Lund University.

*Total number of authors:*

1

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ISRN LUTVDG/TVBM--08/7196--SE(1-24)  
ISSN 0348-7911 TVBM

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# Keeping common knowledge floating

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## Introduction

*Common knowledge* is the knowledge that everyone in a group has (or is supposed to have). It is what everybody knows, usually with reference to the group of people in which the term is used. It can include many types of knowledge: of laws, of how to behave, of how to take care of oneself, of news events etc. However, in this work the term *common knowledge* is limited to such knowledge that students at science and engineering faculties are supposed to have from lower levels of education. It does thus include basic knowledge of mathematics, physics, chemistry and biology, but not the above mentioned types of knowledge. It can therefore be termed *common science/engineering knowledge* that I here abbreviate CSEK.

The general idea with many years of education as we have today in Sweden is that what one learns at a lower level one can recall and use at a higher level. Knowledge builds on previous knowledge, and one does not need to re-learn from scratch over and over again. However, we all know that one cannot always remember what one once learned. One may forget the details and needs to be continuously reminded of what one should know, and that is what this study is about.

I here concentrate on CSEK that students and PhD-students at a science/engineering department should have, i.e. knowledge that they should have from pre-University levels of education. One should for example expect that people at such departments should know that:

- The area of the circle is the number pi times the square of the radius and that pi is approx. 3.14 (mathematics).
- The voltage = resistance · current ( $U=RI$ ) in a simple direct current circuit and that this is called Ohm's law (physics).
- There are acids and bases and that pH is lower for acids than for bases (chemistry).
- Animals respire by consuming oxygen and producing carbon dioxide (biology).

Note that I do not set out to give a knowledge-canon, but it is reasonable to assume that most university teachers would at least assume that their students would know the contents of the textbooks used for ages 13-15. Ohm's law will be used in the following as a typical example of CSEK. In Swedish schools Ohm's law will be superficially discussed in school at ages 13-15 and learned in more detail at ages 16-18 by students with classes in science or engineering.

Ohm's law is a good example of CSEK because it can be of use to any scientist or engineer. Here are some examples from my own experiences:

- When calibrating calorimeters (heat measuring instruments) with electrical heaters one needs Ohm's law to calculate the current from measurements of voltage over a resistance. Such instruments are used both in physical, chemical and biological applications.
- We use a quantum sensor to measure PAR (photosynthetically active radiation) in our work on biological growth on façades. This sensor works by creating a low current that is proportional to PAR. As we want to use a volt-meter to measure the output we have connected the sensor in series with a resistor, using Ohm's law to recalculate measured voltage to current.
- A common method of measuring moisture content of wood is to insert two nails into the wood and measure the resistance of the wood. Normally one uses wood moisture meters that directly give an output of moisture content, but when we are developing such devices in a PhD-project we need Ohm's law to calculate the resistance (moisture content) from a measured current.

Ohm's law is also of interest as it is an example of a general type of physical transport law with the general form:

$$\text{potential} = \text{resistance} \cdot \text{flow}$$

Other examples of this type of equations are<sup>1</sup>:

Fourier's law of heat conduction	temperature difference = heat flow resistance · heat flow
Fick's law of diffusion	concentration difference = mass flow resistance · mass flow
Poiseuille's law of viscous flow	pressure difference = mass flow resistance · mass flow

This report is about remembering or - phrased in another way - about not forgetting. I therefore start with an overview of some relevant findings from memory science, before I describe an investigation of common knowledge, and end with a discussion.

## The human memory

The human memory is fantastic, but it is difficult to understand how it works. The human memory is like a black box. We can observe inputs and outputs, but we cannot look inside<sup>2</sup>. We have to infer how memory works by studying correlations between experimental inputs and outputs. The two most important research tasks in the field of human memory have therefore been to build theoretical models and to make experiments. If similar phenomena as are observed in the experiments as are predicted by a model, the model is good.

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1 There is a difficulty here in that these three laws are normally written in another - and possibly more logical - way than Ohm's law. Ohm's law is usually written  $U=RI$ , but the other laws are usually given in forms parallel to the following way of writing Ohm's law:  $I=SU$ , where  $S$  is the electrical conductance which is the inverse of the electrical resistance. This is possibly more logical as the current is caused by the potential. Internalising that these laws can be written both using conductances and their resistances is important for a full understanding of them, and students often have difficulties with different forms of these equations using resistances or conductances.

2 Not exactly true as neuroscience has several measurement techniques where one can study the working brain. However, most knowledge about human memory is not derived from such measurements.

I will limit the following discussion to what is relevant for the present paper about common knowledge. Most of what is written here is taken from two textbooks in memory science: Baddeley (2007) and Radvansky (2006).

The human memory is usually divided into three parts (although these parts may not correspond to different parts of the brain):

- Working memory - that part of memory that actively manipulates information
- Short-term memory - the more or less active processing and retaining of small amounts of information for short times (typically a minute).
- Long-term memory - holding information for long periods of time; up to a life-time.

In the context of common knowledge it is of course long term memory that is of interest, but when it comes to recalling common knowledge it is also be of interest to discuss working memory.

Long-term memory is divided into different types of memories. Here are some common types (different divisions occur):

- Nondeclarative memories - unconscious memories, for example when someone salivates when he/she sees salty liquorice.
- Episodic memory - memories of events.
- Memory for space and time
- Semantic memory - the memory of general world knowledge.
- Autobiographical memory - memory of one's life.

From the above definition of CSEK it is clear that such knowledge is essentially semantic knowledge.

The following four basic findings from memory research are relevant to the discussion of retrieval/forgetting of CSEK:

**Priming** - When memory retrieval is faster or more accurate because some previous information has directed the memory search in the correct direction.

**Savings** - After something has been learned and forgotten, it is easier to learn it a second time. Thus even what one believes is completely forgotten has left traces in memory.

**Forgetting curve** - The more time that passes since something was learned, the less likely it is that it will be remembered (Fig. 1). This rather disturbing curve indicates that what is learned at one time tends to disappear as time passes.

**Overlearning** - If information is learned over and over again, even when it is possible to recall it without errors, the knowledge will remain in memory for a very long time and does not obey the forgetting curve.

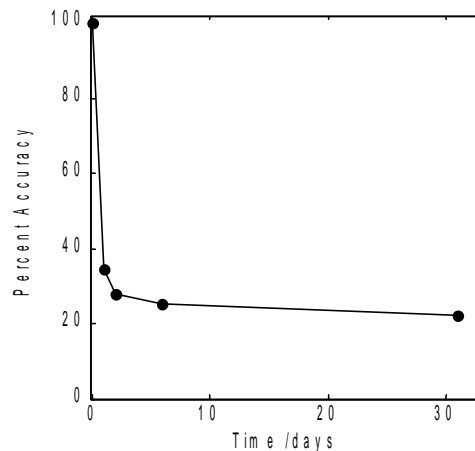


Figure 1. A typical forgetting curve (from Ebbinghaus 1885)

In tests used in memory research it is common to make a difference between different levels of successfully used memory. One can for example make a difference between knowing that one has a certain piece of knowledge (*recognize*) and actually being able to produce that knowledge (*recall*). Another distinction is between *remember* and *know*, where the latter is a reconstructed knowledge based on other memories; a typical example is that I can remember by first day in school, or I know (by reconstruction) that there must have been one such day, even if I do not remember it.

When discussing students and their common knowledge it is also of interest to discuss metamemory - the awareness of one's own memory. This is tricky as we often do not think about how our memory works, but some simplified concepts have been investigated:

- *Judgement of learning* is how well one can predict how well one will be able to recall learned information in the future (these judgements are often poor).
- *Feeling of knowing* is when you feel that you know something, but you can not recall it.
- *Tip-of-the-tongue state* is when you cannot recall a piece of information, but you have a feeling that you are about to recall it.
- *Knowing that you don't know*. It is important to know what you know and what you do not know. Judgements about this are often made very rapidly, and it is usually quicker to respond that something is not known than that it is known.

There is not one clear picture of how the memory works physiochemically or physiologically. Different models have been developed to account for the observed facts, but these models are in most cases quite far away from the “flesh and blood” of the brain. For the present purpose the following not very detailed model of our memory will suffice:

1. Memories are stored in our brain in a network. In this network information is arranged according to - for example - when a piece of information was stored, what other information was stored at the same time, and what connections the piece of memory had with previously

stored memories.

2. When a memory is recalled a search is made through (hopefully) relevant parts of the network. The piece of information indicating what to search for is called a *cue* and the sought information is called the *target*.
3. The results from searching through the memory are *memory traces*, bundles of information. The process of generating the target from the memory traces is called *recall*.

It is not well known how the knowledge is actually stored or how the memory is searched. However, the search is not through the whole memory. If it was like this then it would on average take half the time to recall an existing memory than to answer that one does not know (that one does not have in memory). It is actually quicker to find that one does not know than to recall an existing memory.

## Methods used in this work

### General

I was interested in the concept of CSEK and if an increased thinking about this could improve teaching and learning, especially on the level of PhD-students. Since about four years I run a continuous PhD-student course at Building Materials LTH and neighbouring divisions. One of the main aims of this course is to raise the level of CSEK among our PhD-students and ourselves. In this course we look at different other fields of science, either working together in the group or visiting other departments. This works well and there is a high level of interest in this - at least among the PhD-students that take the course. My first thought was to do a project using this course, but somehow it felt too obvious to discuss CSEK in a course aimed at CSEK, so I chose to work with another PhD-student course on isothermal calorimetry, an experimental technique. This is an intense one week course with lectures and experiments, followed by a discussion of laboratory reports and a written examination about one month after the course.

Isothermal calorimetry is interesting as it is an experimental technique that can be used in nearly all fields of science and engineering. Some of its main areas of use are pharmaceutical science, control of runaway reactions in explosives, cement technology and microbiology - widely different fields. Using one instrument studies can be made in very different fields and during the course the participants - coming from different areas of science - perform experiments in many fields that are not their own field of work. Possibly this is a course, where CSEK is useful. It is for example easier to perform an experiment on acid-base titration if one knows that sodium hydroxide is a strong base and hydrochloric acid is a strong acid. This year I had eight participants at the course and five of these took part in all of what is described below (three participants were not PhD-students or were not from Lund, so they did not come back to the examination day).

The aim of using the methods discussed below was to probe what some students/PhD-students thought about common knowledge. However, this should only be seen as a very shallow study to give me ideas for this work. A limitation here is that it is difficult to have a detailed conscious experience of how your memory works. It is also not possible to remove different types of bias, for example that the participants may have wanted to please me with their answers or that they held back ideas that could be



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seen as criticism of the course.

### Method 1: Quizzes

On Monday and Friday before lunch the participants were given multiple choice questions (quizzes, see Appendix A) to be answered within 15-20 min. These questions concerned what could be included in CSEK of a PhD-student at a department of science or engineering (although it was quite obvious that they would not be able to answer all the questions - I also had to check the questions to make sure that I knew the answers). Both of the quizzes had questions representing different categories, for example mathematical equation, pressure units, acid-bases etc. The quizzes had been tested on about five diploma workers and PhD-students at the department. they all found them interesting and fun (!). Some errors and unclear statements were also found.

The aim of the quizzes was to get the course participants to think about common knowledge. Although the two quizzes had similar questions, the idea was not to test whether there had been an improvement in common knowledge during the course week. I did not collect the results, but only discussed it with each participant.

### Method 2: Diary

On Tuesday, Wednesday and Thursday the participants were asked to write down what came to their mind about the course during 15 min. They were given a paper with some simple headings, so that they could get ideas of where to start writing. One diary template is given in Appendix B (they were identical for the three days).

The aim of the diary-writing was that it would improve the participants recall of the course when I interviewed them about one month after the course. The participants were asked to read their diaries before answering question 2 during the interviews (see below).

### Method 3: Interview

The interviews were conducted about one month after the course. In connection with the examination I met five of the participants one by one and asked them six questions (questions and full result is given in Appendix C; the most important results are summarized below).

## **Results of interview**

The following is a brief account of the result of the study made with the above mentioned methods, but only discussed with reference to the interviews, as quizzes and diaries only mainly were ways of focusing on common knowledge with respect to the course. Generally there was not a lot of result that could be connected to CSEK.

All participants had been thinking about CSEK (not using this term). Most of them in a slightly

Wadsö “Keeping common knowledge floating” ver. 15 May 2008

negative sense: they had at times felt that they were lacking common knowledge. Some mentioned that they had problems with certain knowledge or type of knowledge. All participants were also quite clear about what scientific fields that they felt most secure with, and in all cases their subject of study (for example chemistry) was included among these. Some participants thought that CSEK was maybe not so important anymore as knowledge be easily found on the internet.

An interesting observation with some of the more complex quiz questions - questions that only could be solved by the application of a method - was that some participants solved these questions rather quickly, while other participants took substantial time to come up with the correct answer. They knew that they had the knowledge, but it took a long time to come up with the correct answer.

The following ideas mentioned by participants are all confirmed by memory research:

- Pictures/images can be used to improve memory.
- It is easier to learn things that had been learned before, but forgotten (savings).
- It is easier to remember things that one uses.
- It is easier to remember fun (bizarre) things.

Although pictures/images were used to increase remembering, none of the participants had any clear model of how memory works.

Teachers should not suppose that course participants knows what they “should know”. It is good to start courses or lectures with repetition.

## **Discussion**

### General

The process of building up CSEK in the memory of a student can be divided into the following steps (here Q is a piece of common knowledge):

1. First learning of Q. Typically at age 14-16.
2. Second learning of Q. Easier because of savings. Typically at age 17-19.
3. Repeated use of Q reinforces memory of Q because of overlearning. Typically at age 20-24, but could/should continue for the whole life.

Possibly, the aim of this multi-step learning process is to have the common knowledge firmly grounded in memory by over-learning. The third point is what we can do at the university level by repeatedly mentioning the already-learned knowledge as part of the higher level teaching.

I am certainly not the first person thinking about keeping common knowledge floating - although I have not found much written about it. All teachers see that common knowledge is lacking in many students. Some teachers think that that this is the student's problem. Other teachers find ways of reminding the students about what they should know from lower levels of education.

An assumption that I make (but that I do not prove) is that CSEK is useful in our daily work as students, PhD-students, researchers etc. A person that has a lot of CSEK can work faster as he/she already has the basic knowledge needed to solve problems incorporated in his/her memory. I do not agree with some of the interviewed participants that CSEK is not so important anymore as we have access to all knowledge on the internet. I believe that there is a substantial advantage of having CSEK in one's own memory, ready to use. When it is in our memory - in contrast to just being a fact on a computer screen - it is also connected in the memory network to other memories, for example under what conditions that it was learned, other cases when it has been used and if these uses were successful, other similar (parallel) pieces of knowledge, higher and lower levels in the network hierarchy etc. There is an important difference between knowing Ohm's law and seeing Ohm's law on Wikipedia (although Wikipedia is a great place to learn Ohm's law if you do not know it or have forgotten it). It can be called the difference between internalized and external knowledge. Internalized knowledge is directly useful knowledge, with rich connections to other knowledge. External knowledge is just pieces of knowledge.

The concept of common knowledge - especially in science and technology - is interesting and the present study made it possible for me to look closer at this. The study made on participants at a course was interesting, but failed to give much new evidence of that CSEK is important and that students and researchers can improve their work outcome by increasing their CSEK. However, this is quite difficult and I cannot think of any simple way of quantitatively studying this. One problem is that assessing CSEK through questions will always improve CSEK. This is of course true if the correct answers are given, but I believe that also if the correct answers are not given, questioning will start memory processes that leads to increased CSEK. It is thus probably difficult to assess how CSEK has changed during a period of time. As an example, the quizzes I gave started quite a lot of thinking in me, and I guess also in some of the other participants.

The quiz part of the study was interesting and worked well as a way of introducing the concept of CSEK (and makes it quite clear to most students that it would be an advantage to improve it). Possibly, some of the questions I gave were too difficult to be classified as common knowledge for a PhD-student, but it was not the aim of this study to set down a list of what everyone should know (such a list would be very long).

An interesting observation was that the time to recall how to solve a specific problem varied widely. Two participants - who both would know the answer to a certain question - behaved quite differently. One answered almost immediately, one took a long time (several minutes) before recall. One reason for this could be that the latter student's knowledge was on a lower level than the first (see Fig. 3 below). It is also possible that it was the method of recall that was different. The first participant would answer directly when a seemingly relevant answer was found. The second was maybe not the kind of impulsive person that does this, but he/she liked to think about the answer, e.g., if it was correct, if it could be improved etc. Possibly the “feeling of knowing” can have different strengths and the method of knowing that you know (or do not know) can have different criteria for judging when a fact is correctly known.

On a superficial level my examples of common knowledge may seem to be typical examples of what

one will learn through rote learning; knowledge that will be found on the lower levels of for example the SOLO taxonomy (Biggs 2006), Bloom's taxonomy (Bloom 1956) and Säljö's categories of learning (Marton and Säljö 1997). As an example, look at Bloom's taxonomy of educational objectives. This has three so called domains: affective (attitudes, feelings etc.), psychomotor (motor skills etc.), and cognitive (knowledge, thinking etc.). The cognitive domain of Bloom is illustrated in Fig. 2. Like most other taxonomies, Bloom's is hierarchical, so that learning at the higher levels builds on learning at the lower levels. The present study dealing with CSEK may only seem to be on the lowest level of educational objectives (remember), or possibly also on the second lowest level (understand). However, one cannot, e.g., analyse without remembering and understanding. Possibly these different hierarchical educational models makes us focus too much on the top, not understanding that the bottom is a prerequisite for being able to work on the higher levels. I have met several scientists that have impressed me both by their deep and wide fundamental knowledge and their innovative application of their knowledge. My guess is that for them and for many of our students knowledge comes first and then an experience of being able to use this knowledge leads to an interest for the higher levels. However, just learning knowledge without any purpose or aim is not attractive, so I guess that the first step in a learning process must be an idea that knowledge is useful. For example “the insatiable curiosity that drives the adolescent boy to absorb everything he can see or hear or read about gasoline engines in order to improve the efficiency and speed of his 'cruiser’” (Rogers 1956). First curiosity, then acquire knowledge, finally move on to the higher learning levels.

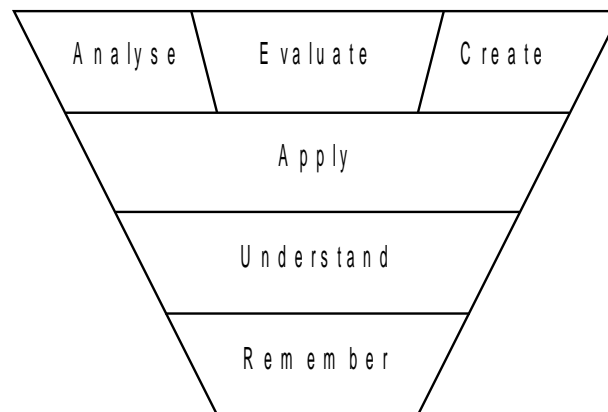


Figure 2. The different categories in the cognitive domain in Bloom's taxonomy. Adapted from a revised Bloom's taxonomy by Anderson et al. (2001).

Let us use Ohm's law again to illustrate Bloom's taxonomy. Just memorizing  $U=RI$  is an example of the lowest level. Such a state can possibly help a person to solve simple questions on an exam but is otherwise not very useful. The second level - understanding - implies that Ohm's law is placed within a larger framework - relation to other similar laws, cases where it cannot be used, alternative formulations etc. On the third level - apply - one can apply Ohm's law to new cases that one has not encountered before. On the highest levels - analyse, evaluate, create - one can go further and deal with such complex operations as classification, analysis of outcome, agreement etc.

Back to CSEK. Working at a high level in any of the learning models requires that basic facts are known. Possibly the higher levels can be seen as methods of using CSEK. It is for example difficult to solve any electrical problems without knowing Ohm's law; a scientist/engineer can not climb the learning hierarchies without fundamental understanding of the world. From the point of my work here I would like to turn the outline pyramid of the revised Bloom taxonomy of Fig. 3 the other way. I would like to have a large base with knowledge and understanding on which the higher levels rest.

### Memory images

From the above discussion of different recall times it seems reasonable to assume that there are different levels of memories; some that are easily recalled as they are commonly used, and some that are difficult to recall or even forgotten. In my interviews I asked whether the participants had any mental images of how their memories worked or how forgetting takes place. I got answers like “One does not forget what one uses”, but not any images (maybe I should have used the word “pictures” instead).

I have a general image of how memory works that I have illustrated in Fig. 3. For me memory is like a sea where memories continuously sink if they are not kept floating (or at least not too far below the surface) by being used. This image/picture is not taken from any textbook, but is my own that I have come up with during this work.

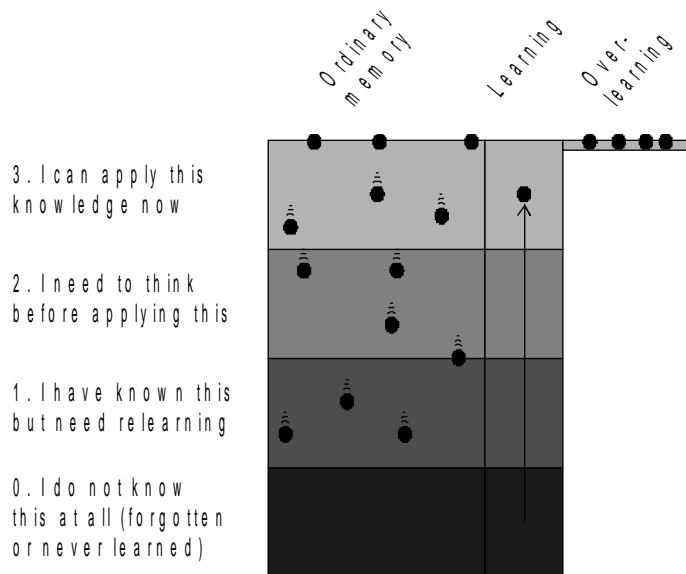


Figure 3. My mental image of how long-term memory works. Memory is divided into four levels; the top level is knowledge that is ready to apply at any time and the bottom level is memories that are forgotten. Most pieces of knowledge are constantly sinking from higher levels to lower levels. Exceptions are knowledge that is presently used and over-learned knowledge. These are shown floating

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on the surface.

In my memory image, the memory has four levels:

0. The bottom level contains all knowledge that I do not know. This is both knowledge that I have never had and knowledge that I have completely forgotten (this possibly conflicts with the concept of savings).
1. On the next level is the knowledge that I have known, but cannot reconstruct by myself. I need my old textbooks, the internet or some other external source of knowledge to reconquer this knowledge.
2. On this level I can reconstruct the knowledge from what I know. This is possibly related to the concepts of feeling of knowing and the tip-of-the-tongue state. Possibly an extreme example of this level is that one of the participants said that he had forgotten the equation for the volume of a sphere, so he derived it by solving the volume integral of the sphere.
3. On the highest level is the knowledge we have at hand at all times. When we are solving a problem we can always use this knowledge. The main idea behind this work is that it is useful to have as much knowledge as possible on this highest level. In Fig. 3 some knowledge is drawn on the surface; this is knowledge that is presently used. When not used it will also start to sink.

If knowledge is not used it will slowly sink to lower and lower levels. Learning is the process that brings knowledge to higher levels (the use of knowledge can also be seen as a way of learning). There is also a high level shelf where over-learned knowledge is placed. This knowledge will never sink to lower levels.

I find images of abstract concepts useful. Such images do not show the truth, but they help my mind. I am not sure that this is true for everybody, but Fig. 3 can maybe at least be used as a way of discussion memory in relation to people's concepts about their own memory.

### Keeping common knowledge floating

How can we help each other to better remember of CSEK? I will here give some suggestions.

#### *Curiosity*

I believe that people who have a lot of CSEK are also very curious about how the physical world functions. They look at a flower and ask themselves “why is it yellow?” (hopefully at the same time enjoying the beauty of the flower). It seems to me that not all our students have this curiosity, which I believe is really important to have for PhD-students and researchers. We should therefore in different ways encourage our students to broaden their knowledge, and not only concentrate on their subject of study. There must be a great difference between learning Ohm's law without being interested in how this relates to the physical world, and learning it and at the same time being curious about for examples under what conditions it can be used? Who was Ohm? What is the resistance of the human body? Why are some materials conductors and other materials insulators?

### *Bizarre facts*

It is known that it is easier to remember unusual facts (called bizarre facts in memory science). Often this is seen as a problem. As an example, most students who fail on their exams can probably recall a lot of detailed facts about movies they have seen or sports facts. The unusual is easier to remember than learning long series of similar things. A key to learning may therefore be to make similar things look different. If one is learning the periodic system of the elements this will be very difficult if the elements are just seen as similar entities. On the other hand if each element has a known “personality” the learning process will be quicker.

It may be a way of making it easier to remember “serious” knowledge by connecting it with curious or unusual details (using bizarre facts may be overkill). For example, it may be easier to remember Ohm's law if one also remembers the following informations about the originator of this law, Georg Simon Ohm (can be found on [www.wikipedia.org](http://www.wikipedia.org)):

- His father was a locksmith in Erlangen (close to Nürnberg in Germany), but he gave him and his brother a solid scientific education.
- When he was enrolled at the University of Erlangen he spent too much of his time time dancing, ice skating and playing billiards, so that his father sent him to Switzerland as a mathematics teacher.
- He published the law that bears his name in a pamphlet called *Die galvanische Kette, mathematisch bearbeitet* in 1827 (“Kette” is circuit).

Although these facts do not say anything about the formulation of Ohm's law, they could possibly give more memory traces by which Ohm's law could be remembered and recalled.

### *Quizzing*

A good way to keep your CSEK active is to solve the more or less scientific questions found in for example some journals. Why not have a board in the coffee-room where people can place such questions. Problem solving is fun and is also a social activity at a department. I even heard of a department which at a party had a quiz about fundamental knowledge in the field of the department. I have activated myself and some PhD-students by posting questions in the coffee room. A good such question to start with is the Monty Hall Problem (see for example [http://en.wikipedia.org/wiki/Monty\\_Hall\\_problem](http://en.wikipedia.org/wiki/Monty_Hall_problem)):

Suppose you're on a game show, and you're given the choice of three doors: Behind one door is a car; behind the others, goats. You pick a door, say No. 1, and the host, who knows what's behind the doors, opens another door, say No. 3, which has a goat. He then says to you, "Do you want to pick door No. 2?" Is it to your advantage to switch your choice?

The answer is quite surprising and not trivial to understand even for most scientifically trained persons (however, one of our technicians found it an easy problem!).

During this work I found that the quizzes I used were quite popular. Why should one solve cross-words

Wadsö “Keeping common knowledge floating” ver. 15 May 2008

when one can answer scientifically relevant questions? However, it is important that one has a good atmosphere at a department before one starts quizzing each other (see next point).

### *Allowed to err*

An important point in this list is that it is difficult to use knowledge if one is afraid of making mistakes. An open atmosphere is of great importance at a scientific institution. Everyone should be allowed to admit “I was wrong” without losing his/her face. This is really the root of all learning: to be allowed to make mistakes and to happily accept when other people correct you.

### *Reading*

Reading is the traditional way of learning and it is a good way. People with a lot of CSEK probably read a lot: scientific papers, newspapers, books etc. Have easy-to-read scientific and engineering journals in coffee-rooms or other places where people meet. Encourage students to read. Improving CSEK does not necessarily mean reading heavy papers. Popular science literature is excellent, especially if it is not in your own field of expertise. Give PhD-students books to read. There are many good popular-science books being published today.

### *Repeat*

Make sure that you give your students a chance to recover the knowledge needed to understand your teaching. This could be in the form of a written material (“basic requisites for the course”), Part of the first lecture, or at the start of each lecture. Note that even small hints may help students recover old memories (this can be seen as priming). If our students need certain pieces of common knowledge, we should quickly repeat what is needed and not presuppose that all students have this common knowledge readily available. If Ohm's law is needed later in a course it is a good idea to remind the students of what Ohm's law is. One can for example do this by showing a slide with Ohm's law, quickly mentioning that this knowledge is important (Fig. 4).




**Two laws we need when calibrating calorimeters**

Ohm's law:  $U=R \cdot I$


Joule's law:  $P=U \cdot I$

Nomenclature

$U$	Voltage (V)
$I$	Current (A)
$R$	Resistance ( $\Omega$ )
$P$	Thermal power (W)



Georg Simon Ohm



James Prescott Joule

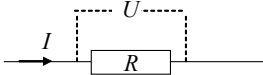


Figure 4. Example of a slide that can be shown at a course in calorimetry to remind the students about Ohm's and Joule's laws of electricity. Note that the slide A. States that this is important for using calorimeters. B. Gives several memory cues (pictures, equations, schematic diagram). C. Is self-contained in that it contains all information needed to learn for example Ohm's law.

### Frameworks

Incorporating a piece of knowledge into a larger scientific framework helps memory. It will give more links in memory, making recall easier. Ohm's law can for example be compared to other laws of similar structure. There is also an interesting history of the order these laws were discovered (Fourier 1822, Ohm 1827, Poiseuille 1838, Fick 1855; however, Fourier based his reasoning on the empirical Newton's law of cooling from around 1700). Another framework for Ohm's law is the other laws of electricity: Joules' (second) law (heat produced in a resistor), Amperes' laws (magnetic field and forces between conductors) etc. Another is the design of electronic circuits where Ohm's law and other rules are used.

### Time for recall

It was clear from my interviews that recall time can vary widely for people who (finally) can recall a certain piece of knowledge. When one discusses seconds in traditional memory studies this concerns recall of simple things, such as recently learned three letter non-word combinations. When we look at recall of not often used common knowledge the situations is clearly different. I see two reasons for this. First of all much more complex knowledge was being asked for than in simple memory tests. Secondly

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the persons that I interviewed may have been nervous or had their thoughts blocked by being forced to discuss their limited common knowledge. Still I believe that it is reasonable to assume that for complex common knowledge the recall time can be quite long, possibly because it takes time to reconstruct the knowledge. Accept that some people are slower in recalling. Possibly they are deeper thinkers than those who answer with the first thing that comes to mind.

## **Conclusions**

I believe that common scientific/engineering knowledge is important. Students and researchers that have a lot of such knowledge can work more efficiently, not having to look up basic information all the time.

It is possible to have routines at a university department that will increase the both PhD-student's and researcher's common knowledge base. One of the more important is probably that lecturers should remind students of what they need to know from earlier courses.

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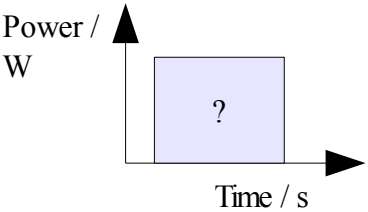
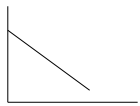

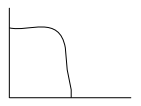
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Appendix A: Quizzes

# Quiz Monday

1. What is the unit of specific heat capacity?	W/K	J/(g K)	K/g	Don't know
2. What is typical of a fermentation process?	37°C	no oxygen	liquid media	Don't know
3. What is the integral under the curve?  	Energy	Force	Pressure	Don't know
4. What is the symbol for entropy?	$S$	$X$	$E$	Don't know
5. Do normal healthy plants respire when it is dark?	yes, but only for a short time	yes, they always respire	no	Don't know
6. How do you expect the concentration of a substance undergoing first order degradation to look?				Don't know
7. Which of these contains most nitrogen?	cellulose	lipids	proteins	Don't know
8. Which of these is a plant?	a moss	a lichen	a fungi	Don't know
9. How do you calculate the heat flux $q$ through a wall with thickness $L$ and a thermal conductivity $\lambda$ ? The temperature difference across the wall is $\Delta T$ .	$q = \frac{\lambda \Delta T}{L}$	$q = \frac{L \Delta T}{\lambda}$	$q = \frac{\lambda}{L \Delta T}$	Don't know
10. How high is the atmospheric pressure (approximately)?	about $10^4$ Pa	about $10^5$ Pa	about $10^6$ Pa	Don't know
11. Which of these statements is <i>not</i> true?	$\ln(ab) = \ln(a) + \ln(b)$	$\ln(a+b) = \ln(a+b) - \ln(a-b)$	$\ln(a^b) = b \ln(a)$	Don't know
12. What is approximately equivalent to 1 atm?	1 mbar	1 bar	1000 bar	Don't know

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13. Which of these salts do not exist?	NaCl	NaNO <sub>3</sub>	NaSO <sub>4</sub>	Don't know
14. What is hydrolysis?	A reaction that produces water	A reaction where water is needed, but not consumed	A reaction that consumes water	Don't know
15. Which of these equations can never be true? ( $m$ is mass, $v$ is velocity, $t$ is time, $L$ is distance, $\rho$ is density (mass per volume)). $\alpha$ is a dimensionless constant.	$L = \alpha vt$	$t = \alpha \rho v$	$m = \alpha \rho L^3$	Don't know
16. What is the pH of a 1 M aqueous solution of NaOH at 25°C?	14	1	0	Don't know
17. What do you get if you integrate $\ln(x)$ ?	$\exp(x) + C$	$1/x + C$	$x + C$	Don't know

# Quiz Friday

1. The heat capacity of a sample is 15 J/K. What does it take to raise its temperature 5 K?	75 W	75 Js	75 J	Don't know
2. Which of these fungi is used in the manufacture of cheese?	<i>Serpula lacrymans</i>	<i>Aspergillus niger</i>	<i>Penicillium roqueforti</i>	Don't know
3. Which of these polymers will soften first if the temperature is increased?	polyethylene	polycarbonate	polypropylene	Don't know
4. The time constant of a process is 2300 s. What is the half-time of the process?	about 2600 s	about 2300 s	about 1600 s	Don't know
5. Which of these is a plant?	a moss	a lichen	a fungi	Don't know
6. How do you calculate the vapor flux $q_m$ through a membrane with a moisture transfer resistance $Z$ ? The vapor content difference across the membrane is $\Delta v$ .	$q_m = \Delta v \cdot Z$	$q_m = \frac{\Delta v}{Z}$	$q_m = \frac{Z}{\Delta v}$	Don't know
7. What is the meaning of the word <i>adiabatic</i> ?	Constant temperature	No heat loss or heat gain	No change in mass	Don't know
8. How high is the vapour pressure of water at 100°C?	about $10^4$ Pa	about $10^5$ Pa	about $10^6$ Pa	Don't know
9. What phenomenon is associated with - for example - a fan blowing air?	natural convection	forced convection	diffusion	Don't know
10. What is approximately equivalent to 1 atm?	7.6 mmHg	76 mmHg	760 mmHg	Don't know
11. Which of these is a strong acid?	HCl	NaCl	NaOH	Don't know
12. "psi" is "pounds per square inches". Which of these statements is true?	1 psi > 1 Pa	1 psi $\approx$ 1 Pa	1 psi < 1 Pa	Don't know
13. What is oxidation?	A reaction that produces oxygen	A biological reaction where oxygen is consumed	A reaction that consumes oxygen	Don't know
14. Which of these equations is always true?	$\sin(x) = \cos(x) + 1$	$\sin^2(x) + \cos^2(x) = 1$	$\sin(x)\cos(x) = 1$	Don't know
15. What is enthalpy associated with?	constant temperature	constant volume	constant pressure	Don't know

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16. Which of these units is <i>not</i> equal to energy?	$\text{kg m}^2 \text{s}^{-2}$	N m	kg N s	Don't know
17. How high is the saturation water vapour pressure at 25°C	about 300 Pa	about 3000 Pa	about 30 Pa	Don't know
18. What is the pH of a 1 M aqueous solution of NaOH at 25°C?	14	1	0	Don't know
19. Which of these salts are most corrosive to steel?	$\text{MgSO}_4$	$\text{Mg}(\text{NO}_3)_2$	$\text{MgCl}_2$	Don't know
20. What do you get if you integrate $\cos(x)$ ?	$-\sin(x) + C$	$-\cos(x) + C$	$\sin(x) + C$	Don't know

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Appendix B

# Diary Tuesday

Lecture

Experiments

I did *not* know...

I did know...

I liked...

I did not like...

## Appendix C

In discussing these results I have called the course participants that I interviewed A-E. I have also avoided all he/she-pronouns.

*1. Had you been thinking about “common knowledge” before this course? For example that you knew that you were lacking some common knowledge or that you were surprised to find that your colleagues lacked such knowledge that you thought everyone had?*

All participants had been thinking about “common knowledge” (not using this expression for it), mostly when they had themselves felt that they missed knowledge that they thought that they should have from previous studies. A specifically mentioned that he had this feeling when he was being “quizzed” by professors and colleagues.

Several participants expressed that common knowledge is maybe not so important anymore as one easily looks things up on the internet.

C mentioned a case where C needed the equation for the volume of a sphere. As C had forgotten it, C set up the equation for a volume integral of a sphere and solved it. C thought of C as a “computer without a hard-disk”.

B - although being a chemist - had difficulties with mol and molar mass. The knowledge is there, but it is not always immediately accessible. Thinking, writing the units etc. solves the problem. B - whose background was engineering - had a feeling that science students had better fundamental (utantill) knowledge than engineering students.

Several participants mentioned that one tends to remember knowledge that one uses.

D had been a teacher at a school where the students had a broad knowledge of arts etc.

E had been surprised to understand that colleagues at a laboratory E visited did not know the basics of Es field, as they were working in a field close to Es.

*2. Did you think about common knowledge during the course? Was there any special common knowledge that you found that you had use for (or that you did not have, but would have liked to have)? Please take a look at what you wrote in the diaries before answering.*

Only some of the participants had any special experiences of either missing or not missing common knowledge during the course week. In some cases this concerned the basic laws of electricity:

$$\text{Ohm's law} \qquad U = RI \qquad (1)$$

$$\text{Joule's first law} \qquad P = UI \qquad (2)$$

Here,  $U$  (V) is voltage,  $R$  ( $\Omega$ ) resistance,  $I$  (A) current, and  $P$  (W) thermal power.



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Certain mathematical skills were also mentioned

The difference between amorphous and crystalline states, enthalpy, Hess law

Most course participants did not have any knowledge of cement and cement hydration, so this was completely new for them.

C mentioned that C had difficulties in remembering the names of equations (for example Ohm's law).

*3. There are a number of different fields of knowledge (corresponding to subjects in school). How do you feel that your common knowledge is in...mathematics, statistics, chemistry, physics, biology, geology, and medicine?*

All participants were quite clear about what scientific fields that they felt most secure with. Naturally, the chemists liked chemistry. The view to mathematics was quite divided: most did not like this subject, but B had become interested in it when B had to study intensively to take a number of math courses. B was interested in biology, because B was interested in plants.

*4. Can we take a look at you quiz?*

D did not like multiple choice questions as D thought such questions were more difficult.

The discussions about the quizzes were interesting. In no case did I feel that the X thought that I was forcing this on them or quizzing them. If I did

I did specially ask how they solved or (if they failed or had not answered) how they would solve the following questions:

- Monday 9 and Friday 6 (can be solved by understanding the physical problem and checking if parameters that should increase the result if they are increased are placed in the numerator (the top part of a fraction) and vice versa).
- Monday 15 (can be solved by checking the units, but one had to know the units of mass, velocity, time, distance and density). D found this simple.
- Monday 11 and Friday 14 (mathematical relations; can be solved by entering simple values and checking which values that give the correct result). Some participants knew the answers by heart “Trigonometrical
- Monday 10 and 12 and Friday 12 (pressure questions; previous knowledge required; cannot be calculated). Few participants could answer these questions.
- Friday 3 (softening temperature of three common polymers). This was a difficult question.

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An interesting observation was that some of those who solved the two first questions did so only after a substantial time of thinking (they did not solve it during the course due to a lack of time). They could solve it but were slow thinkers. For others it was quicker to solve, and for some it was not possible to solve.

Actually, the first three of the above four sets of questions should be solved by most students not by “common knowledge”, but by “common knowledge methods”.

*5. It is obvious that we learn things (common knowledge) in school, and it is also obvious that some of the things we learned, we do not remember anymore. There is thus both learning and forgetting. What is your image of how forgetting takes place? How can one stop forgetting?*

B liked to see pictures of phenomena and remembered better if B had a good picture. “What I remember I have made pictures of. For example trigonometrical laws” and the unit circle. Not only pictures, but dynamic pictures. D also liked to associate ideas with pictures.

If one had learnt something once, it is easier to “learn” it a second time. It is more self-evident when one learns it a second time, possibly seeing it from a slightly different angle.

C said that C forgot when C did not need to remember. Some things C would never forget.

Why do one forget some things more rapidly? Possibly because one preferably remembers things that one finds interesting.

D: Just read: forget fast. Use it: remember. Learning vs. understanding.

D. It is not possible to forget completely. E: It is easier to pick up what one has known before but “forgotten”.

E mentioned that it is easier to learn fun things, for example “Elvis' calorie intake the week he died”.

E thought that things that one needs to learn (are forced to learn) are more easily forgotten.

E thought that what is learned in one course is often displaced by the next course.

*6. As I said earlier, we tend to forget common knowledge. Is it possible for a university teacher to arrange his/her courses so that common knowledge is retained?*

D: It is good to have common knowledge.

A lecturer that starts by repeating 5-10 minutes the most important points of “common knowledge” is good. Only one transparency, but it makes it easier to catch... . Lecturers should not believe that all students have the knowledge that they are supposed to have. If the lecturer gives you some pieces of knowledge, the rest may “fall in place” more easily.

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A teacher should not suppose that everyone knows the easy things. One teacher in mathematics that C had had started from scratch. C had never seen any teacher assume that the students knew so little. Nearly everyone passed the course, even if it was a difficult course.

D mentioned seminars at Ds department. Some were possible to follow as the topic was known or the lecturer started from a low level. Some seminars were held on a too high level.