Chapter 2: What does the evidence say about teaching and learning?

Learning results from what the student does and thinks and only from what the student does and thinks. The teacher can advance learning only by influencing what the student does to learn (Simon quoted in Ambrose et al., 2010, p. 1).

As chapter one explained, a key idea in this book is that teaching should be informed by the evidence available about learning.

So where should we look for such evidence? Over the last twenty years, numerous reviews of research evidence about learning have been published, drawing on different sorts of evidence. Four of the most important such reviews are:

- The American Psychological Association's review of evidence about learning and its implications for school reform (Lambert & McCombs, 1997)
- The US National Research Council's review of evidence about how people can learn so that they can transfer what they learn in formal education to their life outside formal education (Bransford et al., 2000)
- A review commissioned by the government of New Zealand on research evidence about effective teaching of diverse students (Alton-Lee, New Zealand, & Ministry of Education, 2003)
- A review of 800 meta-analyses of statistical studies of learning (Hattie, 2009).

Each of these reviews has a different focus and draws on different types of evidence. Yet what is interesting is the extent to which a common set of ideas emerge from all four. While none of these reviews focus explicitly on evidence about learning in higher education, their implications are nonetheless applicable in university settings.

In this section I will briefly explain five principles of evidence-informed teaching and learning which emerge from these reviews. The five principles are:

- Learning is an effortful process that requires student work
- Students learn when they have opportunities to try, they get feedback on errors, and they can try again
- Students learn when complexity is introduced progressively (dealing with attentional limits – two elements of intelligence)
- Students learn when they have opportunities to practice that are spread over time
- Students learn when they develop the ability to be independent and goal-directed

Learning is an effortful process that requires student work

Benjamin Franklin is known in physics for his description of electrical charge. He is known too for his role in American political life. In learning sciences, he his known as the man credited with the phrase, "Tell me and I forget, teach me and I may remember, involve me and I learn".

One of the key findings of research on learning over the last few decades is that learning is an effortful process which requires work on behalf of the learner – the learner has to be involved in the process. This involvement can take different forms. For example, listening and taking notes in a lecture is itself a form of work – it requires mental effort on behalf of the note taker (Piolat, Olive, & Kellog, 2005). Students will typically remember things a professor tells them for a period of time if they pay attention, but, as Benjamin Franklin correctly pointed out, they will sooner or later forget most of it. If they are to be able to store information and ideas over an extended period of time and to recall that information when they need it, then additional work is also required.

In order to store information in long term memory students need to make connections between the new idea and what we already know. As the American Psychological Association's review of evidence noted:

> Unless new knowledge becomes integrated with the learner's prior knowledge and understanding, this new knowledge remains isolated, cannot be used most effectively in new tasks, and does not transfer readily into new situations (Lambert & McCombs, 1997, p. 17).

'What they already know' might mean prior knowledge from earlier in a course or from prior courses. When a student first comes to study rotational kinematics in physics, for example, they will often find it easier to remember rotational concepts if they make connections with what they already know about translational kinematics (torque is the rotational analogue of force, inertia is the rotational analogue of mass and so on). They may also make wider connections or analogies (power is to energy as velocity is to distance, for example).

'What they already know' might, however, also mean "real world" experiences from outside formal education. For example, students who learn about the ideal gas law might make a connection between the calculations they do on paper and what happens when they pump up a bicycle tyre or what happens when they make a descent when they scuba dive. Indeed, such connections to what students already know are often relatively easy for students to make in science and engineering since these disciplines are concerned with the physical world around students.

While making connections to the real world is always valuable, making rich and vivid connections to the real world is likely to be even more powerful. For example, a student who learning about aqueous solutions in a chemistry class may well find it helpful to remember that when table salt is dissolved in water the Na^+ and Cl^- ions oriented themselves in relation to the polar water atoms. However, if the student goes further and also remembers a time when they tasted salty water then the memory is even more richly encoded. The memory may be of the shock of a mouthful of water when swimming in the sea, or of their grandmother treating a mouth ulcer with warm salty water. Whatever the incident, when a rich, vivid or emotionally charged memory is linked to a fact or idea from their course, they are more likely to be able to recall this idea when they need to.

A student's prior knowledge from the "real world" is also important for another reason: sometimes the things a student thinks they know are wrong. This poses particular problems for learning, because it appears that if misconceptions are not directly challenged, then students can end up trying to make new ideas fit with pre-existing, incorrect ideas. For example, Barker found that many students believe that chemical bonds involves the creation of a "block" of atoms irrespective of the type of the bond (Barker, 2000). Therefore they may assume that, in the same way as H_2O (water) is made up of a series of "blocks" of two hydrogen and one oxygen atoms bonded together, NaCl (table salt) is made up of blocks of pairs of Na^+ and Cl^-. Unless this misconception is identified as such, students can take courses in introductory chemistry and believe they understand bonding, but continue to hold on to this misconception. Similar difficulties are found in most other science disciplines. Indeed, Hestenes, Wells, & Swackhamer (1992) have argued that students hold many incorrect common sense beliefs about physics concepts and that most conventional physics teaching actually does nothing to change these beliefs. This then poses difficulties for students at later stages in their studies.

Making connections between ideas and between ideas and memories, and interrogating these connections to clarify misunderstandings, is known as 'deep processing' of information (Craik, 2002). A second type of strategy that students can use to commit things to their long-term memory is repetition. Since we will return to repetition below it is not necessary to go into detail here, except to say that there may well be things (like definitions or commonly used formulae) that students will have to know by heart and repetition is perhaps the strategy that will work best for them in that context. However, if students are to be able to fluently recall and use information to solve problems at a later stage, deeper processing of information, alongside appropriate repetition, will be crucial.

Deep processing in this way does require the student to work by asking themselves questions such as:

- Can I think of an example of this phenomenon other than the one the professor gave?
- How does this new concept relate to the material we studied a few weeks ago?
- Is the outcome what I would have expected it to be and if not, what does that say about my prior conceptions?

The fact that learning requires students to work does not mean that the teacher is unimportant. In fact, as Hattie has pointed out (and as we will return to below when looking at the importance of building in progression), one of the most effective methods of teaching is quite a teacher-centred method called 'direct instruction' (Hattie, 2009, pp. 204–7). But what makes direct instruction work so well is that it is based on the teacher making the right kinds of inputs at the right times in order that students build the ability to complete tasks independently. This is an idea we will return to again and again.

Students learn when they get feedback on errors, and they can try again to get it right

As we have seen in the last section, students need opportunities to work on new ideas. However, when they do so, they sometimes make mistakes. For example, a student may go to general physics I class and hear a teacher explain the sum of the forces involved when a mass is being pulled across a table top. The teacher explains that, there are certain forces that are not always obvious but which nonetheless need to be included: one of these is the force of gravity, and a second is the normal force exerted by table on the cup in a direction perpendicular to the table. The teacher's explanation is accurate and the student tries her best to accurately take notes while taking in all that is happening: "Invisible forces", she writes, "Gravity, down. Normal force, up". A few days later, she is working on her homework which has six problems, one of which is similar to that she has seen in class, except this time the table top is inclined. She checks her notes and includes the invisible forces in her sum of forces, gravity accelerating downwards and normal force accelerating, not perpendicular to the table, but in the opposite direction to gravity instead. She has made a mistake. What happens next is crucial to her learning.

According to John Hattie, feedback is one of the teaching strategies that has the strongest effect on student learning. He reviewed 23 different meta-analyses of feedback including over 1,200 studies involving almost 68,000 learners. His conclusion was that feedback is "among the most powerful influences on achievement" (Hattie, 2009, p. 173). Hattie noted that feedback works best when it provides information on the learning goals ("Where is the student supposed to be going?"), on their process ("How am I doing?") and on how to make progress ("Where next?"). He notes that feedback which is directed towards the learner (such as “You are doing great!”) typically does not have a very strong impact.

Another important feature of feedback is that feedback typically works best when it is immediate. For example, it has been found that practice leads to the development of expertise when that practice consists of “highly structured activities that are created specifically to improve performance in a domain through immediate feedback” (Hambrick et al., 2014). Other types of practice or experience do not have the same impact on expertise. Of course, the immediacy of feedback is one of the big problems in university settings where teachers deliver a lecture on one day, students do homework sometimes days later and feedback – if it is received at all – comes much later. This has led the lecture to be described as a grossly inefficient way of engaging with academic knowledge and one that is ill-suited to facilitating a learning process:

> [Students] must do the work to render the implicit structure explicit to themselves, must reflect on the relationship between what the lecturer is saying and what they previously understood, and decide if it is different and how the difference is to be resolved. They must … [initiate] their own reflective activities, retrospectively, using their notes of the lecture. Their personal redescriptions are then articulated in tutorial discussions and essays which later elicit feedback from the teacher to complete the ‘discursive’ loop. It can be done, but opportunities for breakdown or failure are numerous (Laurillard, 2002, p. 92).

This problem can be illustrated if we return to the example of a student which began this section. Having made an error in her homework, what would typically happen next for her?

First, it is unlikely that she would get immediate feedback. Feedback, if it comes at all, will probably only come after she has completed the exercises and submitted them for assessment. When the feedback comes it will be some days or weeks after she has made the mistake and at a time when the class and the students have probably moved on to new topics.

Second, the feedback may not be all that specific. In one quite typical scenario, she will receive only a grade which tells her that she got some aspects of the six questions correct and other incorrect. She will be left only with either a general sense that she did “good enough to pass” or that she “needs to go back over” this topic. In such a scenario she will not get any clarity about what her error is and how to put it right.

In the worst case scenario, she will get very little feedback at all. The teacher may make available notes on a solution. If these are detailed it may enable her to see her error. If they are less detailed she may not be able to spot her problem at all. Whether she does the work to analyse the teacher’s solution may depend on whether or not she has already mentally moved on to the next problem set.

So how can we solve the problem of the need for feedback – quick feedback where possible – in contexts of large student numbers? In the next chapter we will look at this in more detail, drawing on three kinds of solutions:

- Using teaching assistants (the ‘traditional’ solution)
- Using technology (the ‘modern’ solution)
- Using the group (the ‘social’ solution)

Students learn when complexity is introduced progressively

One of the key mental attributes that is used in learning is attention: students learn what they pay attention to or, to put it differently, they do not learn facts and ideas that they do not pay attention to. Attention is, however, a limited resource – the human animal can only pay attention to a limited number of things at a given time. Over the last few decades it has become commonplace to say that, on average, people can pay attention to between five and nine discrete pieces of information at any given time. This finding is so well established that it is sometimes called 'Miller's Law' (named after George Miller, the psychologist who first published about the 'magic' number 7 ± 2 [Miller, 1956]). More recent evidence suggests that the number of distinct pieces of information we can process at the same time may in fact be even fewer than seven (Shell et al., 2010, p. 19).

Do all learners only have the capacity to process between four and nine pieces of information? There does appear to be differences between learners in their ability to hold information in mind – differences that are linked to differences in intelligence. However even those who score high on intelligence tests have relatively limited capacity to process different pieces of information. Which begs the question as to how we all cope with the limits of our own capacity to process information.

The first part of the answer is that we learn to do things without having to pay attention to them. Certain kinds of tasks – including complex tasks like driving a car or playing an intricate piece of music – can be learned in such a way that we become able to perform them automatically without having to focus on them. These kind of memories are called procedural memories and, in a neurological sense, are distinct from memories of facts or definitions (Squire, 2009). The early stages of learning procedural memories require a great deal of attention and information processing. You can see this if you think about when you first learned to drive a car and needed to think about clutch, accelerator, brake, gears, steering, mirrors and signals all at the same time and were probably sometimes overwhelmed. Over time, however, the behaviours involved in driving become habitual and they no longer required your attention. In fact, these behaviour can become so engrained that that it actually takes an effort to stop doing them. For example, when you drive in a different country with the steering wheel on the other side of the car you may find yourself unconsciously reaching for the gear lever with the wrong hand. At least some of the things we want students to learn in science and engineering courses are procedural – particular habits of mind for solving problems or for deriving equations, for example, are procedures and can become habitual through practice. More than that, the way in which students approach learning may also be procedural in that they may have habits of mind which automatically kick in when they find themselves in a lecture or an exercise recitation class, or a project group. We will return to these learning habits below.

A second way in which we deal with the limits of our own attentional capacity is by linking together facts or ideas into 'chunks' which make them more manageable. For example, learners can chunk together ideas into mnemonics which are easily remembered. If a student wishes to remember that the sub-shells in an atom are labelled, in order, s, p, d and f, they can instead try to remember that "Sick People Develop Fevers". Now instead of trying to remember four discrete and meaningless pieces of information they link the four pieces into one more meaningful chunk, and therefore remember it more easily. The work of linking new concepts to prior knowledge, which was described above, is in fact a process of making chunks. When a student first meets the idea of thinking about light as a wave, for example, there are many different pieces of information they need to hold in mind at the same time:

- waves are diffracted passing through an aperture;
- the word aperture means a narrow gap or hole;

- the word diffraction means a change in direction;
- the extent of the diffraction depends on the wavelength of the wave;
- it also depends on the size of the aperture;
- waves can be measured in terms of velocity, amplitude, wavelength and frequency;
- frequency is proportional to wavelength but not to amplitude;
- colour is related to frequency and wavelength;
- brightness is related to amplitude;
- frequency is related to energy;
- amplitude is also related to energy;
- and so on.

When a student has first learned these ideas and then meets a problem that asks students to apply the idea of a wave to light, they may struggle as they try to search their knowledge, sort out what information is relevant and what is not and, at the same time, hold the required information in mind and apply it. However, as they work with and organise their thoughts these discrete ideas become organised into chunks: wavelength, frequency and colour become linked together; this in turn becomes linked to diffraction; amplitude becomes linked to brightness; which in turn becomes linked to energy, but differentiated from frequency, and so on. Students organise ideas into chunks of related ideas. Each 'chunk' contains a number of discrete pieces of information, but it is treated by our brain's attention management system as if it is a single piece of information. As a consequence chunking makes handling large quantities of information more manageable.

This idea of chunking provides us with a clue as to how to help students deal with large or complex problems. If a student is faced too quickly with a large number of facts and ideas most students will fail to remember much. If, however, students are introduced to new ideas in more manageable blocks and are given an opportunity to work with these blocks before new information is added, then most students will remember a great deal more. Likewise, if students are faced too quickly with complex problems which requires them to hold in mind and organise a large number of bits of information, most students will fail. If, however, they first get to organise their thinking by working on simpler problems, then more students will succeed when faced with complex problems. In fact, some of my own students set out to test exactly this proposition. They took 296 students and then divided them into two groups:

- A control group which got a single, challenging, exercise question asking them to calculate the area of an irregular shape
- An experimental group which got two simpler area calculation questions which allowed students to identify and practice specific skills before undertaking the same, more challenging, exercise question as given to the control group.

Both groups were given exactly the same amount of time to solve their problem(s). When scoring the exercises, only the more challenging exercise was taken into account. The research team found that the group that had the "warm up" exercises were more significantly more successful in completing the final, challenging, exercise than the group that had only the challenging exercise to complete. This is despite the fact that the experimental group had to answer three questions instead of one in the same time (Babel, Benketaf, & Schukraft, 2014). By progressively introducing the task students had a chance to practice skills in a stepwise fashion so that they were not trying to remember all steps of a process at the same time. In addition, the stepwise approach meant their attention was drawn to certain techniques and which they were then able to put together to solve the more complex task. Without the progression many students were lost in a sea of halfremembered techniques and struggled with holding all of the different elements of a solution in mind at the same time.

One way in which the idea of progression is put into practice in teaching is to see the work of the teacher as being organized into three stages of Present – Apply – Review (Petty, 2006, p. 169):

- Stage 1: The teacher clarifies the goals, then presents information and models ways of thinking and working (Petty suggests that at most this should be 35% of the total learning time)
- Stage2: The students apply this in practice which is initially guided but becomes more independent (At least 60 % of the learning time)
- Stage 3: The progress towards the identified goals is reviewed (at least 5% of the learning time).

A key idea here is that the teacher's role changes depending on which stage they are at in the process:

- Stage 1: the teacher's role is to clarify the goals, to present information, to demonstrate skills and ways of thinking, and to ensure feedback to students and teachers
- Stage 2: the teacher's role is to provide progressively more complex tasks which allow the students to practice, to move from guiding students to encouraging them to practice independently, and to ensure feedback to students and teachers
- Stage 3: the teacher's role is to facilitate the students in summarizing what they have learned and reviewing how they have learned it

When in stage 1 (in a lecture, for example), it is quite appropriate for a teacher to provide information or to show a student how to think about a problem. However, if the teacher is still doing that in stage 2 and 3 (in an exercise or lab session, for example, or in responding to student queries about previously taught material) then there may be something wrong. This implies (a) that the professor or lecturer needs to have multiple skills (for example, presenting, modelling, asking question, managing feedback, encouraging independence, reviewing learning) and (b) that the lecturer or professor needs to choose carefully which skill to use and when. In section II of this book the Present-Apply-Review framework will be used to organize what skills a professor or lecturer should ideally be using and when.

The Present-Apply-Review model is interesting because as well as being well grounded in evidence about learning it also maps quite closely onto the normal practice of teaching and learning in Universities, where presenting (lectures) is often followed by application (in tutorials, labs or exercise sessions). This suggests that rather than having to radically re-think our model of university teaching and learning, what we really need to do is make more minor adjustments which can best aid students learning.

As an aside it is worth noting that the limits of human attention have influenced the way in which the research evidence on learning is presented in this chapter. There are many different ways in which the evidence could have been organized: the American Psychological Association organized the data in terms of 12 principles (Lambert & McCombs, 1997), Alton-Lee organized it into 10 characteristics (Alton-Lee et al., 2003), Ambrose and her colleagues organized the data into seven principles (Ambrose et al., 2010) and so on. Here I have chosen to present the data in terms of five principles: (a) learning involves ***work***, (b) ***feedback*** is important, (c) complexity should be built ***progressively***, (d) opportunities for repetition should be ***spread*** over time, and (e) student ***independence*** should be developed. This is because the limits of human information processing make it is easier to remember five principles than twelve. In doing so I have organized some important ideas (including the role of attention and limits to human attention, the role of deep processing of information, transfer of learning to new context, the distinction between procedural memories and memories of facts and ideas, and others) as sub-themes within the broader framework – in other words I have chunked them with related ideas. As a further aside, if you are looking for a mnemonic device to help you remember these five principles then the phrase *'Working Feedback systems Progressively Spread Independence'* may help.

Students learn when they have opportunities to practice over time

I have noted above the importance of repetition in learning. Whether it is rote memorisation of ideas and facts or whether it is practicing procedures so that they become automatic, repetition is key to learning. This idea is so fundamental to learning research that Shell and his colleagues have elevated it to the status of a rule: "Learning requires repetition" (Shell et al., 2010, p. 24). Nuthall and Alton-Lee, for example, found that if students are exposed to the same idea three or four times over a period of days then typically they are likely to learn it (Nuthall & Alton-Lee, 1995).

For repetition to have maximum effect, it seems to be more beneficial if it is spread out over a period of time rather than all grouped together in the same time period. Indeed Hattie found that spreading practice out over time has quite a strong effects on student learning (Hattie, 2009, p. 186). Hattie also reports that for more complex tasks, spreading the repetition over longer periods of time appears to be beneficial.

This has important implications for how we teach in university. University timetables are often organised so that we teach our courses on a given day each week. The structure of courses often means that after an idea is introduced and treated, we move on to the next topic without building in opportunities or encouragement for students to review or revise the content every now and again. It may be that building in such opportunities to revise over time would have a stronger effect on their learning than spending a great deal of time and effort trying to ensure the perfect presentation in our lectures.

Students learn when they develop the ability to be self-directed and independent

I started with the idea that students need to work if they are to learn. I will finish this overview of learning research by returning to the work students. The final principle is that students need to become able to manage their own learning if they are to learn effectively. This idea is one that emerges clearly from all of the reviews of evidence on student learning. In the words of the American Psychological Association, successful learners are "active, goal-directed, self-regulating, and assume personal responsibility for contributing to their own learning" (Lambert & McCombs, 1997, p. 16).

Why is it that self-direction is so important? As I mentioned above, over time learners develop habits (procedural memories) as to how to go about learning. Having these habits is quite useful for learners; in the same way as they can have a conversation while driving without having to remind themselves how to drive, when they sit down to study a new topic they don't have to use up mental space in thinking about how to study and so they can focus their complete attention on the content at hand. This works fine as long as the learning habits they have developed are well adjusted for the context in which they operate, however it can be a problem when the nature of their content changes. For example, a student coming from secondary school may have managed to succeed by learning off methods for solving different types of problem and choosing the solution to match the problem in an exam. This may well have worked fine for the student as long as the problems are relatively straightforward and are presented in much the same way in the exam as they were in the textbook. When they reach university level, however, the complexity of problems are likely to increase and problems are more likely to be presented in unfamiliar ways. This means that the student's habitual study strategy becomes far less efficient in this changed context. Unless the student recognises the problem and changes their strategy, they will find themselves in difficulty.

Nor is this problem confined to the transition from school to university. Students may well have chosen to study science and engineering disciplines because they like the kind of paper-based problems that they have seen in science class in school, problems which typically have a single correct numerical answer and are completed by an individual. Over the first few years in university it may be that they continue to be confronted with problems that require them to work alone on questions which have one solution. However, they will eventually be faced with more open-ended problems, often in group work settings. Now these students find themselves in a completely new environment. In one small study by some of my students on the thinking of undergraduate students they found that 90% of the civil engineering students the surveyed disliked having open-ended questions posed (Georgiev, Ghaddar, & Hajar, 2015). In another study on an undergraduate course that required group work only 5% of students reported no tension in their group, while 58% reporting at least one source of tension which had a strong impact on their group (Isaac & Tormey, 2014). As students move through their undergraduate programme and into master's study, they are likely to be increasingly faced with problems and challenges that do not match their already developed learning habits. Unless they can spot these problems and change their strategies accordingly they may well struggle.

Facing these problems requires that students are able to monitor their own approach to learning, to spot when it is not working for them, and to develop new approaches. It should be noted that this is not easy to do. As was described above, one of the features of procedural memories is that they operate automatically (think of the driver who finds themselves driving in a foreign country with the steering wheel on the other side of the car and unconsciously reaching for the gear lever with the wrong hand). Once a procedural memory has become automatic, changing the procedure takes a great deal of attention and effort. This is true of habitual learning approaches also. Students who have developed a habitual way of approaching lectures, homework problems or projects will typically find it quite tough to change.

The first step in changing is recognising that a problem exists. This kind of self-monitoring is called 'metacognition'. Metacognition includes both knowledge and skills. The knowledge relates to how people think and learn, and about what kinds of thinking is suited to different kinds of tasks. The skills component involves the ability to plan for learning, to monitor their own learning, and to debug when particular strategies for problem solving or learning do not work (Flavell, 1999). Metacognition is important in part because it is not a 'natural' attribute of a person – it is something that can be taught and learned. For example van der Stel & Veenman (2010) found that students could learn to plan and self-evaluate in learning and that this had an impact upon their performance in mathematical tasks, independent of their measured intelligence. This finding fits well with the broader data: Hattie reports on meta-analyses of learning involving 63 studies of over 5,000 participants. These tend to show that teaching students to think about what strategy they will use to understand material and solve problems has a strong positive impact on students' attainment (Hattie, 2009, pp. 188–9).

But metacognition is not only important because it is associated with increased learning; it is also associated with increased ability of students to transfer their learning from one context to another. I noted above that facts and ideas are easier for students to recall if they have linked them to memories of things the student has experienced (for example, students are likely to remember more about aqueous solutions if they have linked their knowledge of it to an experience of tasking salty water). It is worth noting that memories of facts and ideas are probably always already linked in our mind to memories of at least one experience – that is the experience of learning that fact or idea. This means that we are most likely to remember an idea in a context much like the context in which we learned it, since the idea and the context are associated in our minds. While this can help recall in similar contexts it can hinder recall in dissimilar contexts. I came across an example of this phenomenon recently, when I was discussing a particular statistical analysis with some students working on a project. I asked them what analysis technique they would use, given the data they had. The students told me they had no idea. I probed them further on the type of data they had and how it would normally be analysed and I could feel their growing frustration with my refusal to answer. Eventually one told me, "I guess normally I would use chi-square for this kind of data, but I've no idea what I should use in your class". Chi-square was the appropriate technique to use, and the student knew it, but they had previously never seen it applied in relation to social or psychological data. Therefore they struggled to take what they knew and apply it in a new setting. This kind of incident is not isolated. Most professors and lecturers will have stories about times that students insisted that they could not remember what they had learned in a previous course or could not see how it would be applied in the context of this different course. This problem is called the problem of transfer. If transfer is important within engineering and science programmes (i.e. between modules or courses) it is also crucially important for transfer from engineering courses into the working world after graduation. If students already struggle to remember ideas and facts learned in one course in a different course, what chance do they have of remembering the same idea or fact when they find themselves in a completely new environment in the workplace? This problem of transfer further underlines the importance of metacognition because, when students learn to be metacognitive in their approach to learning, they are more likely to be able to draw on and transfer their learning to new situations without the need for explicit prompting (Bransford et al., 2000, p. 67).

How can we help students to be metacognitive in their approach to their learning?

- In addition to solving problems, homework might include asking students to describe their strategy for solving a specific problem.
- Students can be asked to plan for study and to review their plan with a tutor.
- Feedback (as described above) involves helping students to clarify the goals, to monitor their performance and to set new goals. As such, receiving well-structured feedback aids metacognitive development.
- Certain learning approaches like peer teaching, group work and concept mapping can help to increase metacognitive knowledge and skills.
- Students will find it easier to plan if the goals of the course are clear and explicit.

Conclusion

In the last chapter we explored some of the myths of teaching in higher education which contribute to an inertia in teaching and learning methods. It was suggested that, we should be working to change teaching and learning in university science and engineering, not because change is fashionable, but because we have a good deal of evidence about what works. Indeed, we are not short of changes in higher education: the Bologna reforms, new communications technology and increased accreditation bureaucracy have all lead to considerable changes in higher education practices, but there is not much evidence that these changes have improved learning. What we need, then, is not change for changes sake, but rather a change to teaching and learning practices which are informed by evidence.

So what does the evidence tell us about learning? In this chapter I have outlined five key principles for evidence-informed teaching and learning. They are:

- Learning requires students to be actively engaged in ***working*** with and processing information
- Learning is enhanced by ***feedback***
- Students learn better when complexity is introduced ***progressively***
- Practice opportunities are required, ideally ***spread*** across time
- Learning and transfer is improved when students develop the ability for self-direction and ***independence.***

These five principles can be readily remembered using the mnemonic phrase "Working Feedback systems Progressively Spread Independence".

We noted in chapter two that these kind of general principles are only of limited utility in the day to day world of teaching science or engineering subjects to students. They next need to be translated into practice. It is to this task that the next chapter turns. We also noted in chapter two that, while it is typical for books of this type to begin with a discussion of course design or course planning, the aim here is to put the student learner at the centre of our attention. Instead of starting with the course content, then, we will instead start with the face to face interaction between the teacher and student. Chapter three will therefore ask, how a professor or a lecturer can turn these principles into practice when they are one-to-one interaction with the student.