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Chapter Three

THE COGNITIVE PERSPECTIVE ON LEARNING: TEN CORNERSTONE FINDINGS

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The Cognitive Perspective on Learning – an Introduction

The Importance of Knowledge

Imagine the following scenario: An experienced teacher explains to a class of ten motivated and intelligent elementary school children that the earth is a sphere moving through space. The teacher uses simple, precise, and convincing wording. (S)he explains the similarities and differences between the earth, its moon and the sun. A week later the students are asked to draw a picture of the earth and they produce a number of wrong depictions, including a spherical but hollow earth with people living on the bottom of the inside. Why did the teaching not work as expected?

This situation, loosely based on a study conducted by Vosniadou and Brewer (1992), illustrates that many factors that must interact optimally for learning to occur; none by themselves guarantees successful learning. Even with many positive educational factors being present – experienced teachers, small class sizes, motivated students – learning did not improve when these factors did not lead ultimately to the successful acquisition of new knowledge. In this chapter, we will use this example and others to illustrate how teaching and learning can be better understood and improved by implementing the findings of cognitive science.

Rationale and Assumptions underpinning the Cognitive Perspective

The cognitive perspective on learning is based on the assumption that knowledge acquisition lies at the very heart of learning. Once children acquire new information in learning environments, they are supposed to use that information in completely different situations later in life. This is only possible if they have understood it correctly and stored it in a well-organised manner in their long-term memory.

Cognitive research on learning has the goal of uncovering the mechanisms underlying knowledge acquisition and storage. Many of these mechanisms can be understood as transformation of information, similar to how a computer transforms data by means of algorithms. Therefore, information-processing theories have always been and are still central to cognitive research on learning. Researchers use laboratory experiments and computer simulations of dynamic information-processing models to advance this line of research.

Over the years, however, researchers have broadened their scope and gained insights into how interactions with the social and physical environment shape a person’s knowledge structures. Socially-shared symbol systems such as languages, pictograms, and diagrams are important prerequisites for learning. Computers and the Internet, for instance, are providing new settings for the exchange of information. Researchers also started to recognise the active role students play in learning: how students acquire knowledge depends on their goals in life, their more specific learning goals, their learning strategies, their confidence in themselves as problem-solvers, and other similar factors.

Due to the broad scope of modern-day cognitive science it is ubiquitous in research on learning. When browsing through leading journals that publish advances in research on learning, such as the *Journal of Educational Psychology* or the *Journal of the Learning Sciences*, it is hard to find any study free of ideas or methods originating in cognitive science. Consequently, the cognitive perspective on learning does not compete with other perspectives (for example, the biological perspective or motivational psychology), but instead overlaps with them – usually with huge gains for both sides.

A Paradigm Shift: From the Amount of Knowledge to the Structure of Knowledge

Researchers, teachers, policy-makers, parents and students for long judged the success of learning in terms of *how much* knowledge a student had acquired. In contrast, modern-day cognitive science assumes that the quality of knowledge is at least as important as its quantity (Linn, 2006; de Corte, this volume), because knowledge is multi-faceted. There is knowledge about abstract concepts, about how efficiently to solve routine problems, knowledge about how to master complex and dynamic problem situations, knowledge about learning strategies, knowledge about how to regulate one’s own emotions and so forth. All these facets interact in contributing to a person’s competence. These facets (also called *pieces of knowledge*; diSessa, 1988) can differ in their functional characteristics. They can be isolated or inter-related, context-bound or context-general, abstract or concrete, implicit or conscious, inert or accessible to different degrees. When a persons’ knowledge is structured in detrimental ways, (s)he can have a high amount of knowledge in a domain but may still not be able to apply it to solve relevant real-life problems.

It is commonplace when someone refers to knowledge that they mean only knowledge of facts. In that view, knowledge is something that has to be acquired in addition to other favourable learning outcomes such as conceptual understanding, skills, adaptive competence, or literacy in a domain. In contrast, modern-day cognitive science shows that even these complex competences arise from well-organised underlying knowledge structures (*e.g.* Baroody & Dowker, 2003; Taatgen, 2005). In this chapter as well as in cognitive science in general, therefore, the term “knowledge” is used as a generic term referring to the cognitive bases of many kinds of competence. While some of these competences are brittle and limited (*e.g.* some memorised facts), others are broad, flexible, and adaptive -- depending on the cognitive organisation of the underlying knowledge.

Ten Cornerstone Findings from Cognitive Research on Learning

Because cognitive research on learning spans different disciplines and is methodologically diverse, it is impossible to give a comprehensive review of its outcomes here. Instead, we will present ten cornerstone results from cognitive research, which are relevant to all who try to understand and improve learning. The ten points illustrate well the questions typically asked in cognitive research on learning. Each point also highlights a different aspect of how learners can build up well-organised knowledge structures.

1. It is the learner who learns

Teachers cannot put their hands into the heads of their students and insert new pieces of knowledge. The knowledge a person has can only be directly accessed by this person. As a consequence, learners have to create new knowledge structures by themselves.

Although this seems obvious, the implications are profound. It means that the student is the most important person in the classroom. The teacher typically knows more than the student, has more resources to hand, is more experienced, prepares the classes, provides materials, implements teaching methods, etc. This can give the impression that it is the activity of the teacher that fully determines what students learn and, indeed, teachers' actions influence the quality of instruction to a high degree. However, learning, the main goal of learning environments, takes place in the heads of the students and requires the students to be mentally active. Our introductory example illustrated this: the teacher provided the students with scientifically correct and comprehensive information but what the students stored in their memories was quite different from what the teacher said in class.

As a consequence, teachers need not only good *pedagogical knowledge* about teaching methods and good *content knowledge* about the topics they teach but they also need *pedagogical content knowledge*, that is, an awareness of how students construct knowledge in a content domain (Schulman, 1987). Pedagogical content knowledge comprises insights into the difficulties students often have in a domain and how these difficulties can be overcome. Teachers with good pedagogical content knowledge employ teaching methods not as ends to themselves, but as the means to stimulate their students' idiosyncratic knowledge construction processes. Consequently, future teachers must be trained to use teaching methods flexibly and to adapt them to the needs of their students as well as to the requirements of the content area.

2. Optimal learning builds on prior knowledge

Teachers can only help their students when they know the students' knowledge during the teaching. People generally try to make sense of new information by linking it to their prior knowledge. Thus, what students already know substantially influences their subsequent learning processes.

In the example given in the chapter introduction, the teacher did not account for the students' prior knowledge. Elementary school children have experienced many times that the ground they stand on is flat and that things put on the underside of a sphere fall down. When a teacher tells children that the earth they live on is a sphere, this conflicts with their prior knowledge. When the children try to combine the new information with their prior knowledge, they come up with completely new conceptions of the shape of the earth. Teaching that explicitly addresses children’s prior knowledge and shows how it relates to the new knowledge can avoid these problems.

Making sense of new information by interpreting it in the light of prior knowledge is not limited to elementary school children. It is a fundamental characteristic of all human thinking. Even newborns have some rudimentary and implicit knowledge. This so-called *core knowledge* gives babies intuitions about the basic properties of our world and helps them to structure the flood of perceptions they encounter every day. Other studies with adolescents and adults have found domain-specific prior knowledge to be one of the most important determinants of subsequent learning (Schneider, Grabner, & Paetsch, in press). Prior knowledge in a domain is usually an even better predictor of future competence in that domain than intelligence (Stern, 2001). The importance of prior knowledge is not limited to specific content domains. Even learning in formal domains, for instance, mathematics or chess, depends heavily on prior knowledge (Grabner, Stern, & Neubauer, 2007; Vosniadou & Verschaffel, 2004). Studies have found interactions between students’ prior knowledge and learning processes in various academic disciplines, including physics, astronomy, biology, evolution, medicine, and history (Vosniadou, 2008).

Students’ prior knowledge stems from various formal and informal contexts including everyday-life observations, hobbies, media, friends, parents, and school instruction. Students have different parents, use different media, and have different interests. Therefore, even students in the same class can possess vastly different prior knowledge. This requires teachers to adapt their instruction not only to the competence level of their classes but also to the individual prior knowledge of their students. Since this knowledge changes during instruction, teachers must continuously assess and diagnose children’s knowledge during class. This approach differs substantially from the traditional practice of first teaching a topic and only then assessing children’s knowledge in a final test (Pellegrino, Chudowsky, & Glaser, 2001).

Recently, educational researchers have developed a number of tools and techniques for assessing students’ knowledge during on-going instruction (so-called *formative assessment*; *e.g.* Angelo & Cross, 1993; Wiliam, this volume). All teachers should have a working knowledge of the diagnostic methods appropriate for their subject and age group. It is also important to view the mistakes students make as signs of on-going knowledge construction and use them to diagnose these processes (Stigler & Hiebert, 1999).

3. Learning requires the integration of knowledge structures

The fact that students’ knowledge stems from a wide variety of sources gives rise to another issue: learners often fail to see the abstract relations between pieces of knowledge acquired in superficially different situations (diSessa, 1988). For example, when children hear that the earth is a sphere but do not understand how this relates to their prior knowledge, they might simply assume that two earths exist - the flat ground they stand on and a spherical earth flying through the sky above them (Vosniadou & Brewer, 1992). This phenomenon has been observed in other age groups and content areas, too. When children already hold incorrect conceptions in a domain and the correct concept is taught to them without linking it to their prior knowledge, the children can simultaneously hold incorrect and correct concepts without even noticing the contradiction.

The child will activate one of the two concepts depending on the nature of a situation (*e.g.* conversations with friends in everyday life vs. tests in school), (Taber, 2001).

A weaker form of this phenomenon can be observed when a person holds several correct pieces of knowledge without seeing how they relate at an abstract level. For example, making clothes dirty and then washing them puts them back to their original state. The task 5 + 3 - 3 can be solved without computation by simply stating 5 as the answer. Taking three cookies out of a jar and putting three other cookies into it later, brings back the original number of cookies. From b - b = 0 follows a + b - b = a. Most adults can see easily how these different statements relate to each other - they all describe an inverse relation between two operations. However, empirical research shows that children often do not see this (Schneider & Stern, 2009). Dirty cloths, numerical computations, cookies, and algebraic equations -- they each belong to different domains of learners' lives and thus, commonly, to different domains of their thinking.

Teachers should remember that the same content domain can look highly relational and well-organised from their point of view but, at the same time, highly fragmented and chaotic from their students' point of view. Helping students to gradually adopt the perspective of experts by successively linking more and more pieces of knowledge in the students' minds is a major aim of teaching (Linn, 2006). All instructional practices focusing on abstract relations are helpful for achieving this goal. For example, diagrams can help to visualise connections between concepts; students often discover abstract relations by comparing similarities and differences between superficially different examples of the same abstract idea.

Integration of knowledge across subjects can be fostered by projects in which students discuss the same phenomenon (*e.g.* the shape of the earth) from the perspectives of different subjects (mathematics, physics, geography, history). Equally, perhaps even more, important is for teachers to point their students toward the multitude of small links that exist between subjects during class. Proportional reasoning (*i.e.* one variable as the quotient of two other variables), the use of symbol systems (*e.g.* diagrams or formulas), the usefulness and limits of computers, the interpretation of empirical data, differences between scientific reasoning and everyday thinking, how to contribute productively to a discussion -- these are just some examples of the many topics that are relevant to many subjects and that can be used to integrate knowledge structures across subject boundaries. Lastly, good communication about lesson content between all teachers who participate in the students' educational programme is a precondition for knowledge integration across subjects.

4. Optimal learning is about acquiring concepts, skills and metacognitive competence in a balanced way

An important aspect of integrating students' knowledge structures is helping them link their concepts and their procedures. Concepts are abstract and general statements about principles in a domain. For example, students with good conceptual knowledge in algebra understand that a + b equals b + a (*i.e.* principle of commutativity). Students with good conceptual knowledge in physics understand that density is mass per unit volume and what implications this has, for example, for whether objects float or sink in liquids. Procedures differ from concepts in that they are rules specifying how to solve problems. They are like recipes in that they specify the concrete steps that have to be executed in order to reach a goal. Good procedures can, for example, enable students to efficiently solve a quadratic equation or to construct a toy ship which will actually float on water.

In the past, philosophers and educators debated the relative importance of concepts and procedures (Star, 2005). Some argued that only procedures help to solve the problems we encounter in everyday life; that practising efficient use of procedures is thus the most important learning activity while abstract concepts are of little help. Others responded that such routine expertise is too limited and brittle for solving the complex and dynamic problems of real life, claiming that education should focus primarily on teaching concepts; the assumption being that a person who fully understands the concepts behind a problem can easily construct a solution when necessary. Today, there is widespread agreement that concepts and procedures are both important parts of competence (Siegler, 2003). Well-practiced procedures help students to solve routine problems efficiently and with minimal cognitive resources. These resources can then be used instead to solve newer and more complex problems on the basis of a deeper conceptual understanding.

It is not enough, however, for students to have just concepts and procedures. Students also need to see how concepts and procedures relate to each other (Baroody, 2003; Rittle-Johnson, Siegler, & Alibali, 2001). For example, building a toy ship from household materials can improve one’s concepts about buoyancy force and how buoyancy relates to object density, because the practical problem offers many opportunities for testing the implications of the concepts and to connect abstract ideas to concrete experiences. On the other hand, the acquisition of abstract concepts helps learners to understand why their procedures work, under what conditions they function, and how they can be adapted to new problem types. The teacher in our introductory example had a difficult task because the shape of the earth is a content area with many concepts but only a few procedures that could help students explore and experience the concrete meanings of these concepts. One possible solution in such cases is the use of physical models, for example, a globe.

The mutual reinforcement of concepts and procedures can be strengthened further by helping learners to reflect on their knowledge acquisition processes. This is usually labelled *meta-cognition*, that is, cognition about one’s own cognition (Hartman, 2001). Meta-cognition helps students actively to monitor, evaluate, and optimise their acquisition and use of knowledge. Without meta-cognition, students do not notice inconsistencies in their knowledge base. On the other hand, meta-cognition is not an end in itself but serves as a means to knowledge acquisition. Thus, meta-cognition and knowledge acquisition in concrete content domains are inseparably intertwined and cannot be taught or learned independently of each other.

5. Optimal learning builds complex knowledge structures through the hierarchical organization of more basic pieces of knowledge

Different people all with high competence in a domain can have very different knowledge structures, depending on their individual preferences and their learning histories. One characteristic is nevertheless common to the knowledge of all competent persons: it is structured in hierarchical ways. This is true for perception, language processing, abstract concepts, and problem-solving procedures.

Tihs sencente mkeas snese to you, eevn thgoh the lretets are sclrabmed up, because people do not encode letters independently of each other. Instead, people use hierarchic memory representations with letters at the basic level and words at a higher level. Thus, knowledge about letters helps to identify words and knowledge about words helps to identify letters. By means of this mutual support, intact knowledge on one level can help to correct wrong or incomplete information on the other level.

The same applies to taxonomic knowledge (Murphy & Lassaline, 1997) and more complex concepts (Chi, Slotta, & Leeuw, 1994). Imagine a person without any background knowledge about the American Goldfinch. When this person is told that the Goldfinch is a bird, (s)he immediately knows many things about it. Birds lay eggs, so the Goldfinch lays eggs. Birds belong to the superordinate category animal, and animals breathe, so the Goldfinch breathes. Birds are animals that are distinct from mammals, so the Goldfinch does not feed milk to its young.

The hierarchical organisation of knowledge is also important for procedures. For example, planning a house is a complex problem consisting of many sub-problems. Novices with little prior knowledge can quickly get lost in this complexity. In contrast, experts will break the big problem down into a series of smaller and more manageable sub-problems (*e.g.* first planning the position and shape of the outer walls, and then planning the inner walls on each floor). In a next step, experts will break these problems down into even smaller and manageable sub-problems (*e.g.* first planning the staircase and the bathrooms and then fitting in the other planned rooms), and so forth. The result is a large number of small and easy-to-solve problems. In the literature, this process is also referred to as *task decomposition* or *goal decomposition*. A large number of empirical studies and computer simulations demonstrate the ubiquity and power of this problem-solving approach (*e.g.* Ritter, Anderson, Koedinger, & Corbett, 2007).

6. Optimally, learning uses structures in the external world to organize knowledge structures in the mind

Teachers are supposed to make sure that students acquire rich, well-balanced, well-organised knowledge structures and yet they cannot put these knowledge structures directly into their students’ heads. So, what can teachers do? They can provide students with optimal learning opportunities by preparing well-structured learning environments (Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001). This strategy works because structured information in the learners’ social and physical environment will help them to structure information in their minds. There are many ways to provide structures on many different levels in learning environments. Some examples are the temporal organisation of a curriculum, the order of ideas or tasks introduced to the students in a lesson, the outline of a book, the informal social structures of groups of students working together, the design of work sheets, technical terms, formulas, diagrams, and specific formulations in the teacher’s language. We will take a closer look at some of the most important examples in this section.

Teachers can only prepare structured learning environments to the degree they are aware of the structure of the content area they are teaching in, the structure of students’ prior knowledge, and the knowledge structures the learners are supposed to build up during the teaching. This is often hampered by the fact that curricula are formulated as a list or table specifying what content is to be taught at what grade level. This could result in teachers thinking linearly about instruction as sequences of contents or teaching methods. While this may be correct so far as it goes in terms of timing or sequencing, it has to be completed with a second perspective: teachers must be aware of the hierarchical structure of the knowledge they try to communicate (see Point 5).

Language is one of the most powerful tools for providing structure in a learning environment. Grammatical constructions can emphasise the relations between concepts and procedures (Gentner & Loewenstein, 2002; Loewenstein & Gentner, 2005). By carefully choosing their words, teachers can emphasise that two pieces of knowledge conflict with each other (*e.g.* "…whereas…"), that one idea explains or justifies another idea (*e.g.* "…therefore…"), that two variables form a proportion (*e.g.* "…per…"), and so on. The use of labels for groups of objects can emphasise commonalities of the objects within each group and differences between objects not in the same group (Lupyan, Rakison, & McClelland, 2007). For example, in everyday life, people often speak of the "sun and the stars in the sky". This might cause children to think that the sun is basically different from stars. By labeling the sun a "star", a teacher can help children integrate their knowledge about stars and about the sun.

A second function of language is the structuring of classroom discourse. Discussion between students is important because it helps them exchange ideas and learn about the existence of different perspectives and opinions. This helps teachers to assess their students' knowledge. It is important to keep in mind, however, that the discourse serves a clear purpose within a lesson. By asking good questions, and opposing, re-phrasing, or summarising students' statements, teachers can structure a discussion; they can make sure that it is not an aimless collection of different statements but a goal-directed social construction of new insights (Hardy, Jonen, Möller, & Stern, 2006).

Structuring time well also provides structure. A semester, a topic within a semester, a lesson within a topic -- all need to be structured effectively with an orienting and motivating introduction, a main part and a consolidating summary. This sounds easy, but it means that teachers have to use a considerable amount of their time planning ahead, because it is not enough for them to just prepare one script and stick to it. Teachers can only react to the unfolding social interactions in their classrooms when they improvise to some degree while simultaneously providing structure and guidance. This requires teachers to anticipate the potential reactions of their students and prepare appropriate responses.

Technical equipment can be a great help for structuring learning environments (Winn, 2002). PowerPoint presentations, movies, audio recordings, experiments, computer programmes, and interactive internet pages provide structure by stimulating some thinking processes while preventing others. An important rationale is that even the best technical equipment can never replace but only complement teachers and face-to-face interactions in class (Koedinger & Corbett, 2006).

Technical equipment is a tool used by a teacher to stimulate specific learning activities. Thus, technology is not generally good or bad for teaching. It is unproductive when it is used as a means in itself. It is productive when it is used skillfully as a tool for fostering students' construction of specific knowledge structures (cf. Mayer, this volume). For example, replacing a teacher monologue about the earth as a sphere by Internet pages with the same content is of little help. Using an interactive computer animation showing the earth from different perspectives, on the other hand, can help students to understand that the same earth looks very different when you are standing on it from when you see it from a point in space thousands of kilometers away.

Finally, providing structure in learning environments implies that teacher and learners must be aware of the learning goals (Borich, 2006). Whether students are practising routine tasks, working on a cross-subject project, or seeing a movie, they will learn little unless the teacher uses learning goals to focus the students' attention on the relevant aspects of these complex situations. Students need to understand the reasons behind their learning activities.

It took mankind several thousand years until it discovered some of the contents taught in middle schools today, for example, the laws of classical mechanics, the Cartesian coordinate system, or the mechanisms of photosynthesis. These ideas were not developed by average people but usually by a genius, often after years of intense research. Normal learners cannot be expected to acquire many of these concepts through incidental or informal learning, for example, during visits to a museum or to a factory, participation in a community project, or during their various hobbies. Instead, they need structured and professionally-designed learning opportunities that carefully guide their knowledge construction. Informal learning settings can still be helpful for acquiring self-regulatory competence, optimising motivation, practising the application of knowledge etc. From a cognitive point of view, however, informal learning experiences can only complement but never replace more formal - more structured - settings for learning.

7. Learning is is constrained by capacity limitedations byof the human information-processing architecture and capacity

The architecture of human cognition has some basic properties relevant for the design of optimally structured learning materials (Sweller, Merrienboer, & Paas, 1998). These properties include *working memory*, where information is actively processed, and *long-term memory*, where information is stored. Working memory has a limited capacity, and information stored in working memory is quickly lost when it is not updated within seconds. In contrast, long-term memory has an almost unlimited capacity and can retain information for days or even years. New information can only enter long-term memory through working memory. However, not all information is transferred from working memory to long-term memory because new information is filtered. The more meaningful, more important, or more frequently-recurring the information, the more likely it is to be transferred from working memory to long-term memory. Teachers can make information more meaningful and more important to students by linking it to their prior knowledge and by using emotionally appealing examples that demonstrate the usefulness for solving real-life problems.

Due to its limited capacity, working memory is a bottleneck for the transfer of knowledge to long-term memory. Even though learners build up a complex web of knowledge in their long-term memory, their working memory can only hold up to about seven pieces of information at a time (Miller, 1956). Therefore, taking up information from the environment and integrating it with prior knowledge already in long-term memory requires a series of many small steps carried out in working memory (Anderson & Schunn, 2000).

Teachers can aid this process by reducing unnecessary working memory load (see Mayer, this volume). Structuring information hierarchically helps, because it enables learners to hold a superordinate piece of knowledge in working memory instead of its many subordinate components. For example, someone who tries to remember the number 20012009 has to hold 8 digits in working memory. Others might be able to subsume the number (or 01202009 depending on the notation in common use) under the superordinate label *date of Obama's inauguration as President of the United States*. They can remember all the digits by storing this one label in working memory. Thus, structuring knowledge hierarchically, or *chunking* as it is called in the literature, can help overcome working memory limitations.

Unnecessary working memory load can further be reduced (cf. Mayer & Moreno, 2003) if pieces of information that can only be understood together are presented together. For example, a coordinate system with several line graphs is easier to understand if each graph is labelled directly rather than if this same information is given in a key under the coordinate system. In the latter case, learners have to jump back and forth between the coordinate system and the key. This creates an unnecessary working memory load. For the same reason, when a formula with many new symbols is presented in a book, the symbols should be explained directly next to the formula and not somewhere else. When a text explains a complex figure, it can help to present the text in auditory form, so the learners can look at the figure while listening to the text instead of jumping back and forth between a printed figure and a written text.

Another way to reduce unnecessary working memory load is to keep learning materials as simple as possible. For example, when a quantitative function can be visualised in a two-dimensional graph, it should not be presented in a three-dimensional figure just because the latter looks more impressive. Likewise, computer-presented slides should not contain any more cartoons, cross-fading effects, or animation than necessary to grab the attention of the audience. The same applies to language: the simpler the language used to explain complex relations, the better and faster students will understand such concepts.

When students are learning to solve new problems with multiple steps (*e.g.* equation systems), their working memory quickly reaches its maximum capacity. This is because the students must not only execute the concrete steps necessary to solve the problem but they must also find the abstract principle that underlies the problem solution. In this case, working memory load can be reduced by worked-out examples. By studying solutions instead of generating them, students can focus solely on the big idea behind the solution and not worry about carrying out the concrete solution steps at the same time (Renkl, 2005).

8. Learning results from the dynamic interplay of emotion, motivation and cognition

At the beginning of cognitive science research in the 1960s, many researchers imagined human cognition to be similar to information processing by a computer. As a consequence, little attention was paid to the emotional and motivational aspects of human cognition. Since then, however, things have changed considerably. Motivation and emotion are now recognised as important determinants of thinking and learning.

Many laypersons and teachers, and maybe even some researchers, tend to see motivation as the motor that drives learning. When the motor is running, learning takes place; when the motor stands still, no learning occurs. Empirical research shows that there are at least three things wrong with this picture. First, motivation gradually and dynamically changes: it is not either "on" or "off". Second, while motivation drives cognitive learning processes, it also results from cognitive processes such as learning and reasoning about one's own competence. Third, the picture creates a false dichotomy between cognition and motivation. The two concepts have to be broken up into their constituents to understand how they influence each other. Students' learning goals and goals in life, their thoughts about their own competence, students' attributions of academic success or failure on various potential causes, and students' interests and hobbies all contribute to the complex interplay of cognition and motivation.

For this reason, good learning environments do not treat motivation as a motor that simply has to be started up in order for knowledge acquisition to take place. Instead, they treat knowledge acquisition and motivation as multi-faceted and dynamically interacting systems that can strengthen or weaken each other in a multitude of ways.

9. Optimal learning builds up transferrable knowledge structures

Even when students are motivated and build up sophisticated knowledge structures, this does not necessarily mean they acquire competence that is useful for their lives. There are many more concepts and procedures that are relevant for life than can be taught in school. Teachers do not know for sure which pieces of knowledge will be relevant for their students later in life because life is so diverse and unpredictable. Two potential approaches for solving this problem are discussed in the scientific literature - the training of domain-general competences and fostering knowledge transfer.

The training of domain-general competences (*e.g.* intelligence, working memory capacity, or brain efficiency) is based on the idea that these competences help to solve a very wide range of problems independently of their domain. It follows that if time is set aside from other subjects in school and used for the training of domain-general competences, students might gain competence that is not restricted to specific content areas. This idea appeals to many because it seems to be an efficient way of acquiring competence - practising a single competence and then being able to solve a limitless number of problems. Decades of intense research have shown, however, that this hope is not realistic. Domain-general competences, such as intelligence, are extremely difficult and costly to train. They can be increased only within narrow limits, and the increases are usually not stable over time. Even more importantly, domain-general competences do not help to solve a problem when a person lacks knowledge about the problem at hand and its solution. The highest intelligence, largest working memory capacity, or the most efficient brain cannot help to solve a problem if the person has no meaningful knowledge to process.

A related misconception is that formal training, for example, learning Latin or mental exercises with more or less randomly chosen content (commonly called "brain jogging") makes subsequent learning in all content domains more efficient. According to the empirical research so far, this is not the case. Even though the brain is plastic, it cannot be trained with just any exercise as if it was a muscle (Chi, Glaser, & Farr, 1988; Stanford Center on Longevity & Max Planck Institute for Human Development, 2009). For all of these reasons, teaching domain-general competences at the expense of concrete content knowledge is an ineffective instructional approach (Stern, 2001).

A more effective alternative for broadening competences is to teach concrete content knowledge in ways that aid subsequent transfer to new situations, problem-types, and content domains. This flexible kind of expertise, however, does not develop on its own. Practitioners and researchers alike are often surprised at how frequently learners who have competently mastered one problem are then unable to solve basically the same problem when only small aspects of its presentation change (*e.g.* the wording or the illustrative context) (Greeno & The Middle School Mathematics Through Applications Project Group, 1998). Yet, the ability to apply knowledge flexibly and adaptively to new situations is one of the most important characteristics of the human mind (Barnett & Ceci, 2002).

Teachers should do all they can to help learners use this potential to its fullest extent (Bereiter, 1997). One important precondition for transfer is that students must focus on the common deep-structure underlying two problem situations rather than on their superficial differences. Only then will they apply the knowledge acquired in one situation to solve a problem in another. This can be accomplished by pointing out to students that two problem solutions require similar actions (Chen, 1999); by using diagrams to visualise the deep-structures of different problems (Novick & Hmelo, 1994; Stern, Aprea, & Ebner, 2003); by fostering comparisons between examples that highlight their structural similarities or differences (Rittle-Johnson & Star, 2007); and by the careful use of analogies between phenomena in different domains (Gentner, Loewenstein, & Thomson, 2003). People are less likely to transfer isolated pieces of knowledge than they are to transfer parts of well-integrated hierarchical knowledge structures (Wagner, 2006). The more connections a learner sees between the educational world of learning environments and the outside world, the easier the transfer will be.

Teachers should thus make use of meaningful real-life problems whenever possible (Roth, van Eijck, & Hsu, 2008; The Cognition and Technology Group at Vanderbilt, 1992). In addition, parents, museums, media, computer learning programmes etc. can foster knowledge transfer by illustrating to learners the relevance of scientific concepts and approaches in the context of everyday life (Renkl, 2001; Barron and Darling-Hammond, this volume).

10. Learning requires time and effort

Building up complex knowledge structures requires hard work over long periods of time for both students and teachers. Consequently, time and effort invested in practising problem-solving and extending one’s knowledge base are among the most important factors influencing the success of learning (Ericsson, Krampe, & Tesch-Römer, 1993).

Some claim that students can become competent *without investing serious time and effort* if only the teaching was more fun, more project-based, more brain-adequate, more computer-based, or if it occurred earlier in life. None of these claims is justified by the results of empirical research. These features can assist learning to some degree if they are used in the right amount and at the right times. However, none of them can substitute for the acquisition of complex knowledge structures nor even guarantee that knowledge acquisition would actually occur. To the extent that they do stimulate learning, it is still as time-consuming and difficult to achieve as learning processes generally are (cf. Anderson & Schunn, 2000). Learning can and should be fun, but it is the type of fun that it is to climb a mountain -- not the type of fun it is to sit at the top and enjoy the view.

Conclusions

Only certain areas of cognitive science investigate learning processes. Since it is impossible to summarise all the findings from cognitive science or even just from cognitive research on learning in a single book chapter, we have presented ten cornerstone findings from cognitive research on learning to illustrate typical questions, approaches, and outcomes in this field. The ten points focus on knowledge acquisition, because cognitive research shows that well-structured knowledge underlies more complex competences including conceptual understanding, efficient skills, and adaptive expertise. Learners lacking such knowledge are unable to take advantage of the multitude of social, ecological, technological, cultural, economical, medical, and political resources that surround them.

The ten points described in this chapter have direct implications for the design of effective learning environments. Since they are derived from general principles of how the human mind works, they can be applied to all age groups, school forms and subjects. Good learning environments: stimulate learners to be mentally active; address prior knowledge; integrate fragmented pieces of knowledge into hierarchical knowledge structures; balance concepts, skills and metacognitive competence; provide expedient structures in the environment that help learners to develop well-organised knowledge structures; and present information adequately for efficient processing in the human mind given its inherent limitations for processing (such as limited working memory capacity). Good learning environments foster transfer between content domains as well as between the learning situation and everyday life. They do not try to circumvent the hard work that learning entails. Instead, they maximise motivation by making sure that the content to be learned is meaningful for the students, by clarifying the goals of their lessons, by emphasising the relevance for life outside of the learning environment, and by sensitivity to their students' interests, goals, and self-perceptions.

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