Successful Engineering Lecturing based on Neuroscience

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Abstract

Many engineering professors teach their classes without having received previous training in psychopedagogy and neuroscience. While a few of them have received some form of pedagogical training during their academic career, the vast majority have not acquired any training in the field of didactics, that is, in the science of teaching. Teaching is a difficult task, and teaching effectively is even more difficult. Much literature exists on different teaching-learning methodologies that have been empirically tested in engineering studies. However, practically none of these works make reference to the main factor in any learning process: how does the human brain learn? This paper analyses learning from the perspective of its three main phases (motivation, attention, memorization), and how these phases should be addressed in a lecture, since many of the Engineering classes at universities around the world are given as lectures. The current knowledge of neuroscience is used in the paper to provide twelve recommendations on how a lecture should be successfully given in Engineering Degrees. For the selection of these twelve tips we use two criteria: they must be relevant in a lecture, and they must have a neuroscientific basis, which is explained in the framework of the paper. The relationship between the twelve tips and the seven principles of good practice in undergraduate studies enunciated by Chickering and Gamson has also been established. The relation of each tip with the learning phases to which it refers is explained, and an example of how to apply it in a lecture is given. This paper presents a new way of working in engineering education: how to apply the knowledge provided by neuroscience to the teaching-learning process. This work provides some ideas about how this can be done.
in a lecture, but it is also necessary to conduct experiments to validate the effectiveness of the twelve tips proposed herein. It is likewise necessary to carry out similar work for other teaching methodologies such as PBL, flipped classroom or service-learning. The future of education cannot be developed without taking into account the functioning of the human brain or by applying educational practices that are unsupported by scientific evidence of their effectiveness.

Keywords
Neuroscience; neuroeducation; motivation; attention; memory; emotions, human brain; lectures.

1. Introduction

Many of the classes taught at engineering degrees around the world are given as lectures, and thus many schools provide general lecturing guides, (for example: https://uwaterloo.ca/centre-for-teaching-excellence/teaching-resources/teaching-tips/lecturing-and-presenting/delivery/lecturing-effectively-university). Several publications provide advice on what should and should not be done in a lecture to increase teaching effectiveness, and helpful books on what university teachers should do to achieve that aim [1, 2] can also be found in the literature. However, none of these publications provides evidence to justify such advice from a neurological point of view. This paper presents twelve tips for delivering a successful Engineering lecturing based on current knowledge of Neuroscience.

At the end of the 19th century, experts like William James [3] were already affirming that the most important factor in education is to make our nervous system an ally instead of an enemy. At present, however, there still persists a restricted vision in which the role of the brain in educational work is an implicit assumption that fails to accord the brain the importance it deserves. This outlook limits critical reflection about the methods traditionally used in teaching and learning, and whether or not these methods effectively enhance the acquisition of new knowledge.

Even now in the 21st century, the teaching modality of past centuries (and millennia) still prevails: students are mainly taught by means of expository sessions that require only memorization and repetition. The adoption of traditional expository methodology as the predominant method of teaching makes students mere passive recipients of information, which hinders their motivation and learning. The expository method involves learning by reception, which originates in the old conception, attributed to John Locke (S. XVII), of the human being as an entity that comes into existence with a mind regarded as clean slate or a tabula rasa on which nothing is written. In lectures, students are not required to make any discoveries of their own beyond the comprehension and assimilation of content that can merely be reproduced on demand [4]. On the other hand, we know that meaningful student learning should be the goal of every teacher. Meaningful learning is distinguished by two characteristics: (1) content can be related in a substantive way to students' prior knowledge, and (2) students should adopt a positive approach to this task, and give their own meaning to the contents they assimilate. The teacher's task consists in programming, organizing and sequencing the contents, so that students are able to learn effectively by fitting new knowledge into their previous cognitive structure, and thus avoid purely repetitive or rote learning [4]. It is therefore clear that current teaching systems must be improved by adapting them to contemporary needs and focusing on lifelong learning.

This paper does not defend the use of the lecture as against active learning methodologies. One of the purposes of educational innovation is to enhance the lecture, and the aim of this paper is to demonstrate the feasibility of using this teaching methodology by taking into account the educational paradigm of neuroeducation. While several weaknesses are identified within the traditional practice of exposition, such as student passivity, limited participation, and discouragement of the search for information and critical analysis, lectures also have advantages, one of which is that they enable learning activities with large groups in an economically profitable way. Nevertheless, it is possible to control the content developed in class and the time spent there in a more effective manner, as well as the class structure and the dynamics employed. Lectures are an appropriate way of teaching, but is this also the case for learning? What activity takes place in the brain during a lecture?

In 2010, an MIT team showed that the amplitude and frequency of brain waves dropped appreciably when a student attended lectures [5]. The level of brain activity in class was similar to that recorded when the student was watching television, or even that measured in some phases of relaxation during sleep. On the
other hand, brain waves were observed to be very active when the student was working in the laboratory, studying or doing an exam. This experiment provides a neural justification for the low efficiency of the classroom expository method. Learning must therefore be designed in accordance with the functioning of the human brain [6]. This does not mean that students do not learn in a lecture. The brain adapts to any learning system, even if it is bad, since its main function is to help human beings adapt to the environment.

Executive functions [7, 8, 9] are a set of cognitive skills whose main objective is to facilitate the adaptation of the individual to new situations: concentration capacity, impulse control, operational memory, planning and organization capacity, cognitive flexibility, emotional self-regulation [10], decision-making capacity, capacity of self-reinforcement, conscience, etc. Executive functions are fundamental for achieving appropriate academic learning from childhood onward. A correct development of executive functions is essential for the learning that students must undertake at university. However, when students enter university at the age of 17 or 18, some of them have yet to develop their capacity for planning, organization, and regulation of behaviour. These young people are more likely to fail subjects during their first year, since they do not have the necessary brain mechanisms to meet the academic demands of university. Moreover, most teachers are not aware of this fact, and therefore do not provide their students with the necessary tools or advice to help them plan and organize their studies.

Neuroeducation is a science that combines the results of neuroscience, pedagogy and psychology [11, 12]. Neuroscience bases its results on autopsies, experiments with people who have some disease or injury to the brain, and on different types of brain scans (MRI, EEG, PET and CAT) as well as the most recent studies on the structure and functioning of the brain [13]. Teaching and learning are intricate processes that depend on both individual and social characteristics, so we may never arrive at a unifying theory. Nevertheless, psychological theories about learning and human interaction are still fundamental to understanding these processes, since they explain some aspects of learning that enable the design of policies and practices aimed at improving learning.

This paper seeks to make the most of all this knowledge about the functioning of the brain in order to propose a list of tips to guide and improve the learning of students in lectures. The rest of the paper is organized as follows: Section 2 describes how the learning process is carried out. Section 3 presents a list of twelve recommendations for successful teaching in a lecture. Section 4 presents some reflections on the ideas presented in this work, and Section 5 concludes the paper.

2. The learning process

Unlike other mammals, evolution has made humans give more importance to emotion and less importance to the sense of smell, our most primary sense. This has occurred due to changes in the limbic system, which is responsible for the management of emotions. The necessity of human beings to learn how to survive and evolve has in turn led to the development of curiosity, which spurs us to investigate our environment and ourselves. The brain needs to understand its environment in order to be able to adapt to it, thereby strengthening the ability of the individual to survive [14]. Thus, the brain endeavours to interpret events in order to foresee possible threats or danger and thereby anticipate such situations. The mechanism that evolution has designed to perform this task is known as pattern recognition [15], which enables human beings to organize and understand the chaos that surrounds us, and therefore predict future events [16]. Pattern recognition allows us to respond in a timely way to external events in order to avoid danger or, for example, to recognize edible foods. In fact, the brain may be regarded as an instrument specialized in pattern recognition. Pattern recognition has three phases: (1) Recognize a new pattern, (2) Improve the recognition of an existing pattern, and (3) Re-recognize an already known pattern. Each of these phases triggers the release of dopamine, the neurotransmitter that enables the brain to undergo successful adaptations. The release of dopamine produces a pleasurable sensation, and so fixes learning in place. Some authors identify this feeling of pleasure with fun [16], which gives rise to the notion that fun is a consequence of the brain's adaptation to pattern recognition (learning). This conclusion may help to explain why students look for patterns to solve problems rather than trying to understand them (dopamine is released when students find a pattern), or why Gamification techniques are successful in the classroom (after playing, the brain’s reward or feel-good system is activated). Within gamification techniques, video games help us to learn and concentrate, and to perform multitasking in a fascinating way, as Daphne Bavelier explains in the TED talk "Your brains on action games" [17]. This is because action video games activate attention networks.
Figure 1 shows the most relevant factors in the learning process: Motivation, Attention and Memorization. Motivation and attention are closely related to each other. If students are motivated, it is much easier for them to pay attention. Memorization depends on the emotions involved in learning. The following sections explain this figure in detail.

![Diagram of learning process factors](image)

**Fig. 1 Most relevant factors in the learning process**

### 2.1. Motivation

When something motivates us, we experience a sense of pleasure that allows us to enjoy what we do. When the brain is motivated, it works more efficiently, a phenomenon that has a physiological explanation [18]. Motivation provides extra energy to the brain in the form of glucose and oxygen. Neurons receive this energy, which is processed by their mitochondria. This extra energy allows the individual to work for longer without getting tired.

Motivation is an essential factor for success in studies [19], and in general in any task that the human being intends to carry out. In order to motivate oneself, it is necessary to have an objective that responds to a specific demand and which presents a challenge. If there is no challenge, motivation cannot exist. The objective must involve emotional aspects, and it is perhaps for that reason that social recognition is one of the objectives that gives rise to greater motivation.

Two types of motivation can be considered: intrinsic motivation ("motu proprio") and extrinsic motivation (favoured by the environment) [20]. A fundamental mechanism for arousing motivation is curiosity, because it activates the regions of reward in the brain [21]. Thus, an effective way to achieve motivation is to stimulate curiosity (which in fact is the mechanism that triggers intrinsic motivation). Extrinsic motivation can be transmitted between students (for example, through collaborative work) or from teacher to student on the basis of mirror neurons [22]. The practical significance of mirror neurons from the perspective of teaching and learning is discussed further in Sections 3.1. and 3.2.

### 2.2. Attention

Attention is the capacity that allows us to focus our mental resources on certain aspects of the environment and on the execution of our actions. In short, attention is the ability to concentrate on a specific task. Attention follows curiosity involuntarily and involves a selection of stimuli and behaviour control [23, 24].
Attentional time (total time during which the student’s complete and almost continuous attention in class is required) is not the same for the different stages and ages of human development. By determining the times of the brain required for maintaining attention at each age may help to adjust the actual times of attention during classroom learning. This would enable the effectiveness of teaching-learning to be improved at any educational level. The MOOC (Massive Online Open Courses), for example, are courses based on short-term activities (10-15 minutes). It has been proven that, with these types of activities, students achieve a complete focus of attention throughout the activity [21].

Attention is a selection mechanism that comes into play when choosing a particular source of external stimulation, a series of internal thoughts or a specific course of action. Attention has been related to voluntary control and effort, as opposed to well-learned automatic behaviour [25]. In that sense, attention can also be classified in terms of whether it is voluntary or involuntary. Involuntary attention is achieved thanks to the intrinsic motivation or the reinforcement provided by external stimuli. The seven principles for good practice in undergraduate education identified by Chickering and Gamson [26] can also help to achieve involuntary attention. Voluntary attention, on the other hand, requires a personal effort, and motivation is therefore essential to maintain this type of attention. The development of executive functions has a determining influence on the individual's ability to obtain voluntary attention, since this type of attention requires cognitive control. Students must learn how to control impulsivity, how to defer gratification, and how to develop self-control (emotional and behavioural self-regulation) to avoid procrastination.

2.3. Memorization

No learning can be achieved without some memorization. Herman Ebbinghaus, in the late 19th century, was the first scientist to demonstrate that it was possible to study higher mental functions in a scientific laboratory [27]. Ebbinghaus demonstrated that:

- Meaningful material is remembered ten times longer than meaningless material (contextualized learning).
- The information studied with motivation requires less time to be reproduced (accessed).
- The first and last repetitions of lists are remembered better than the rest of the repetitions. This phenomenon is known as the serial-position effect [27].
- The more time we spend trying to memorize information, the longer it takes to forget.
- The memorized information is forgotten very quickly during the first hour after learning. The forgetting curve reduces its slope as time passes. Nine hours after learning, we will have forgotten approximately 65% of the information, and after twenty-four hours, we will have forgotten two thirds of what we learned.
- The mechanism of memorization requires repetition. In other words, the material studied must be reviewed with a certain frequency. "Forgotten" information can be relearned much faster and more easily than the first time if the learning exercise is repeated.

On the other hand, Garrett [28] postulated that when a subject is memorized in one “cramming” session (massed learning), more repetitions are required than if the effort is distributed over two or three spaced sessions (spaced learning). The frequent use of information facilitates its evocation, and makes it resistant to interference. Recent studies have shown that repeated practice helps to generate new neurons and neural connections in the hippocampus [29].

2.4 Emotions

The brain is able to recognize significant information using the limbic system, which is responsible for managing emotions. The information that provokes an emotional and/or motivational reaction is more likely to be remembered than information of a neutral type [30, 31]. Thus, any learning that does not incorporate emotions is interpreted by the brain as irrelevant, and the brain forgets it [32]. From the above, it follows that learning must involve emotion. Emotions are known to influence a student’s academic performance in traditional learning [33, 34].
Emotions are automatic reactions that the brain generates against stimuli or situations that are of special relevance. Once emotions arise, they can be redirected (emotion-reason interaction) [35]. The amygdala is the brain structure which integrates the emotions with their corresponding response patterns, provoking a response at a physiological level or the preparation of a behavioural response.

One of the different classifications proposed for primary emotions classifies them into two types [36]:

- Personal: disgust, anger and fear
- Socially shared: sadness, happiness and surprise

Fear is an emotion that has been used by many civilizations throughout history (“spare the rod and spoil the child”), and even today is used by some dictatorial regimes in certain parts of the world. However, using fear as the main emotion to learn has negative consequences. The brain associates learning with fear, and when learning is no longer essential, the brain does not want to do it. Therefore, other more positive emotions must be exploited for learning.

Most human beings are reluctant to change because change involves learning new things. A part of this reluctance may be due to the fact that from childhood on we have been evaluated by means of exams, and failure means that we have been negatively marked by the system. Thus, some people associate learning with fear of failure, which gives rise to an aversion to learning and therefore to accepting changes in their environment. We must seek to remove from our students their fear of making mistakes, which is a scourge in our society and, in particular, in our educational system. Mistakes are penalized, when in fact mistakes are a fundamental feature of every learning process.

In terms of learning, one of the most effective emotions is surprise. Surprise arouses curiosity and activates the thalamus, an organ that plays a highly important role in motivation and attention. Surprise in the classroom can be achieved in many ways: by changing the subject or activity, for example, by talking about something inconsequential that has nothing to do with the class, or by telling a story, as shown in Section 3.4.

2.5 How the human memory system works

While it is not the purpose of this paper to describe the functioning of the human memory system in detail, we believe it is necessary to provide a general description. A complete description about how memory works in the classroom can be found in [37]. The outside stimuli captured by our senses are stored in the short-term memory, where the information remains for only a few seconds. It then passes from the short-term memory to the hippocampus, the memory management centre, where it can be stored for years before definitively passing into the long-term memory. The amygdala intervenes in this transfer of information in such a way that learning related to emotions is recorded more "strongly", both in the hippocampus and in long-term memory. Figure 2 shows this process.
Nevertheless, emotion is not the only factor involved in the consolidation of learning. Other factors also intervene in a decisive way [38]: Feeding, Cognitive strategies and Sleep.

With regard to food, the right diet can increase the capacity for concentration and executive attention, both of which are fundamental for learning. Intellectual performance improves significantly if nutrients that favour the functioning of neurotransmitters are included in the diet. It is not the purpose of this paper to address what may be regarded as the right diet, since much information on this subject can be found in the literature [39].

Cognitive strategies are the means by which students organize their actions using their intellectual capacity and, according to the demands of the task they wish to perform, to guide their thought processes towards solving the problem. According to Derry and Murphy [40], these strategies involve a set of mental activities that students use in a learning situation in order to facilitate the acquisition of knowledge. They are behaviours observable directly or indirectly during the learning process, and involve knowing what to do in order to learn, knowing how to do it, and being able to control it while thus engaged. Cognitive strategies are closely related to executive functions. Cognitive strategies are skills that are retained once they have been learned, and students can generalize them to other junctures and situations, a process that enables true learning: that is, learning how to learn. Some students do not possess these strategies or use them inappropriately, which prevents them from processing the information properly. Enhancing students’ cognitive strategies ensures a better quality of learning [41].
The last of the key factors in the consolidation of memory is sleep. The sleep time after the fourth or fifth hour is mainly dedicated to the consolidation of learning. This is a highly important factor that students must take into account in order to optimize their learning. Many students study intensively on the day or days before an exam, thus reducing sleep periods. When these periods are shorter than four or five hours, the brain cannot effectively retain what it has learned, so these students will be unable to consolidate what they have been studying.

3. Presentation: Twelve tips for teaching in a lecture

This section sets out some proposals that teachers can use to improve student learning in their lectures [42]. The proposals are based on the ideas presented in the previous sections. We use two criteria for the selection of these twelve tips: they must be relevant in a lecture, and they must have a neuroscientific basis, which is explained in the framework of this paper. Whenever possible, these ideas will be related to the seven principles for good practice in undergraduate education as defined by Chickering and Gamson, [26], which in some environments have been called "the seven principles of quality teaching". These principles are as follows:

- **P1:** Encourage contact between teachers and students
- **P2:** Encourage cooperation among students
- **P3:** Stimulate active learning
- **P4:** Provide feedback on time
- **P5:** Dedicate time to the most relevant tasks
- **P6:** Communicate high expectations to students
- **P7:** Respect different talents and ways of learning

3.1. Enter the class with a smile and energy (P1)

The way a teacher enters a class is extremely important because it predisposes students to what they will learn. Teachers should create an appropriate emotional climate in the classroom from the very beginning. By entering the class with a smile and with energy, teachers transmit motivation thanks to the mirror neurons. Mirror Neurons are activated when we undertake an action or when we see another person perform it [22]. Mirror neurons are necessary for understanding the actions of other people and for learning new skills by a process of imitation. From the educational point of view, the most interesting feature of mirror neurons is that they appear to be the mechanism by which motivation can be transmitted. Motivated teachers can therefore pass motivation on to their students.

If, on the other hand, they make their entrance looking dejected, sullen, or sad, they transmit negative feelings. A good emotional climate improves learning [43]. The attitude of the teacher throughout the class is also crucial. He or she should maintain a positive attitude, creating empathy with the students. Such an approach generates prosocial attitudes and favours the creation of a good bond between the teacher and the students (P1).

3.2. Ensure that students know and interact with each other from the first day (P1, P2)

The bond between teacher and students (P1) and between students themselves (P2) must be established in the first days in order to facilitate learning [21]. This bond will make it easier to awaken emotions during the learning process in the classroom.

As mentioned in Section 2, emotions are key to learning. Emotions may be aroused by any type of event, but most of the time they involve other people as well as the person experiencing the emotion. When students relate to their peers, the emotions they experience can be transmitted thanks to mirror neurons: students can pass motivation on to their classmates when they work collaboratively.

In this way, students who are not motivated or predisposed to learn a particular subject may draw inspiration to study it from their classmates (thanks to mirror neurons), as well as the emotion necessary to fix learning. Moreover, the sustained interaction with colleagues during collaborative work is an example of involuntary
attention reinforcement provided by external stimuli. Involuntary attention is maintained when students are enjoying the activity in which they are involved. This entertaining experience generates dopamine, which in turn produces a sensation of pleasure.

In this sense, peer learning has been shown to be more effective than individual learning [44, 45]. Group activities should be programmed to achieve this type of learning, which can be facilitated by collaborative learning strategies such as "problem-based learning" or "project-based learning". In the case of lectures, the teacher can let the students discuss in pairs (or groups) about what they learned at certain moments of the class.

3.3. Causing surprise in students (P1, P2, P3, P4, P5)

The beginning of a class is a very important moment. A catalyst is required to arouse curiosity and produce surprise. Curiosity activates the regions of cerebral reward, which leads to motivation and attention, and triggers the release of dopamine in the brain, which helps students focus attention and inspires them to look at a situation in new ways [46].

Surprise is a primary emotion that arouses curiosity in students and causes them to pay attention. Spraying surprises on students can serve to galvanize them, even though the surprise may have little to do with the class. The surprise should be introduced either at the beginning of the class or during the course of the same. A surprise that was sprung several hours before has little or no effect. Surprise stimulates the attention that is essential for learning. Since surprise is a primary emotion, learning in such an atmosphere has a high probability of being retained and remembered. Some strategies for awakening and encouraging curiosity, as well as for facilitating meaningful learning in class, are outlined below [21]:

- Start a class with something provocative.
- Present a daily problem to "awaken" the student
- Create a relaxed atmosphere that invites dialogue (P1, P2).
- Allow time for students to develop an argument or find the solution to a problem (P1, P2, P3). In this case, the teacher should help them by modulating the search (P4, P5).
- Try to get students to anticipate what is going to be explained (P1, P3, P4).
- Introduce into the class elements that imply incongruence, contradiction, novelty, surprise, bewilderment, or uncertainty (P3).
- Reinforce the merit of a good question or intervention (P1, P3, P4).
- Introduce an unexpected activity for students in class
- From a concept to be addressed in class, tell a story related to the concept that has nothing to do with the subject (P1)

Let us consider a possible example of the application of introducing an unexpected activity for students in class. Suppose that the teacher is going to address in class a topic that the students have previously encountered, at least in part, in another subject. If the teacher exposes the subject in a highly formal manner it may be boring for the students, since a lecture of this type will not provide them anything new beyond a mere review of the topic. Furthermore, it may often happen that students are only able to vaguely remember the topic or unrelated parts, or even be unable to relate the topic to aspects they have studied in other subjects. A methodology/activity that the teacher may use in this case is to tell the students that, since the class is about a topic with which they are already familiar, they are going to teach it to themselves. The teacher can then use the Socratic Method to ask students specific questions about the topic. The purpose of these questions is to stimulate the students to consider their answers carefully and enable them connect the knowledge they already have on the subject with knowledge they may regard as unrelated. This activity constitutes a surprise for students, who are not used to actively participating in lectures. This example may also serve for the advice detailed in Section 3.9.

3.4. The power of good stories (P1)

The brain loves good stories [47]. The importance of stories is so important for human beings that, even though it is mentioned in the final point of the preceding section, we believe that it merits a specific tip. Humans have evolved as literary animals: we are social beings who tell stories about other people and for other people [48]. Furthermore, we are surrounded by stories throughout our daily lives (news, novels,
movies, series, songs, plays, video games, etc.). A significant part of our leisure time is dedicated to immersing ourselves in the stories of others.

Our ancestors gathered around bonfires to recount their adventures, express their thoughts and listen to those of the rest of the tribe. Today, we meet with co-workers for breakfast or lunch and with friends for dinner or drinks. In these meetings, we share stories and experiences (personal or belonging to other people) concerning work and our own emotions. Dunbar, Marriott, & Duncan [49] showed that 65% of the conversation time between human beings is devoted to talking about social issues.

Storytelling is one of the human characteristics that has remained throughout the history of humankind across all its different cultures. Archaeologists have found folk tales written in Sanskrit, Latin, Greek, Chinese, Egyptian and Sumerian that promote social cohesion between groups and have served as a method to transfer knowledge between generations. Today we relegate storytelling almost exclusively to the field of entertainment, but stories are a very valuable learning tool [50], because among other things they arouse curiosity and attention [1].

Stories also arouse emotions in the listener, emotions that, as explained in Section 2, are fundamental to learning. Stories give rise to changes in the biochemistry of the brain. An emotional story that engages the interest of the listener, for example, causes the brain to generate cortisol and oxytocin. Cortisol is a hormone that focuses our attention, while oxytocin is a hormone associated with empathy. In the case of learning, if the teacher tells a story that awakens interest in students (P1), their brains begin to generate cortisol, which is conducive to attention and predisposes them to learning material that is addressed in class immediately after storytelling.

A consequence of the above is that starting the class by telling a story is beneficial for learning, even if the story has nothing to do with the class. Moreover, a story introduced at any time during a lecture serves to renew student attention. The question is: What constitutes a good story? Freytag [51] defined the phases of a successful story in what he called a dramatic arc. According to the dramatic arc, a good story consists of five distinct stages: Exposition, Rising Action, Climax, Falling Action and Denouement. A story told in accordance with these phases makes it more interesting to students and helps teachers to focus their attention. The stories must be lived and felt, and for that reason, personal stories have the desired effect. That is why many good speakers begin their talks with a personal story in order to engage their audience.

A possible example of the application of this advice is to tell a story on the subject being studied, but developed in a completely different context. For example, imagine that the influence of cosmic rays on an electronic device is being studied (i.e. electromagnetic interference in the transmission of radio frequency waves, or interference that causes errors in the transmission of data in semiconductor memories). Students can be asked if they think that cosmic rays also influence human beings, for example. The teacher can then explain that the cosmic rays that constantly bombard our planet also cause mutations in cells, and that the results of these mutations that best adapt to the environment are those that survive and reproduce best, as Darwin stated in his theory of evolution. Therefore, those annoying cosmic rays that interfere with our transmissions are largely responsible for our presence in this class right now.

3.5. Maintain student motivation (do not demotivate) (P1, P2, P3, P4, P5, P6, P7)

Avoiding discouragement is just as important as motivating; if the students are unmotivated, the teacher must present them with thought-provoking but realistic and sensible expectations to enable them to complete the proposed learning activities, thereby enhancing their self-esteem. It is important to remember that, according to the self-determination theory [52], in order to motivate students the teacher must offer them a certain degree of autonomy in carrying out tasks, train them beforehand in the task to be undertaken so that they are able to complete it, and endow the task with meaning within the context of the subject.

Teachers must know how to maintain the motivation of their students, both those who are intrinsically motivated and those who are extrinsically motivated. Since attention follows on the heels of motivation and on curiosity, maintaining the latter is as essential as the former. In addition to maintaining the motivation of students, teachers should avoid any action that might discourage them. Some examples that the teacher may consider in sustaining student motivation are given below:
• Encourage personal relationships, both between students and teachers and between classmates themselves (P1, P2). This involves encouraging communication. Students should feel that the teacher is an ally with whom it is easy to communicate. If teachers erect a wall between them and their students and conduct their classes in a one-way manner, with little or no possibility of student intervention, students will become demotivated. Encouraging personal relationships helps to create an atmosphere in class that is conducive to learning.

• One of the main causes of demotivation in the world of work is the figure of "the boss". In class, the teacher is "the boss", but should avoid behaving like a figure of authority in order to prevent demotivation (P1).

• Failure to recognize the work done by students is also an important factor in demotivation. When students do a good job, whether in or outside of class, when they ask a good question or intervene well in class, teachers should acknowledge the merit. As a result, students feel valued and are less prone to discouragement (P4).

• Fear plays an important role in demotivation. Teachers must take care to see that students are not afraid of failing a subject and help them discover the enjoyment involved in learning what they study. Thus, punishing students when they make mistakes may only contribute further to a feeling of demotivation. Punishment may be formalized verbally (a censorious response or a frown from the teacher), or physically (the mistake has a negative influence on the final grade). In any case, punishment generates the fear of making a mistake, and therefore fear of learning. Teachers should encourage student participation in class, encouraging them to intervene without fear of being wrong. This may be done by underplaying mistakes and explaining why they have occurred. The teacher could also use an anecdote to highlight a real case in which mistakes were made before the final solution was successfully reached.

• Students sometimes set themselves goals that are unrealistic or too ambitious. In such cases teachers must act as tutors to bring students to the realization that “the best is the enemy of the good”, and convince them to adapt their expectations to their own abilities, and to what the teacher expects from them, rather than to what the students expect of themselves. In the same way, teachers should take care not to create false expectations in the students, especially in the first days of class. This is not incompatible with communicating high expectations to students (P6); expectations can be high, but above all, they must be realistic.

• Lack of autonomy is a further factor in demotivation. The executive functions of the brain enhance autonomy, but if autonomy is undermined by the type of activities carried out in the classroom, it can lead to demotivation. Teachers should therefore encourage students to be autonomous (P3).

• Routine is a great enemy of motivation. Should teachers conduct all their classes in the same way, the ensuing routine will lead to boredom, and boredom will result in demotivation, as will be seen in Section 4. Thus, even though the lectures are of a formal nature, they must be different from each other (P7).

• An excessive workload is another cause of demotivation. Teachers must quantify very carefully the amount of work that students are required to do, as well as the time assigned to each task. An excessive overall workload or the assignment of a large amount of work in a short period of time contribute to student demotivation. European degrees measure the students’ work in ECTS credits. An ECTS credit is equivalent to 25-30 hours of student work during a semester. A subject involving 6 credits, therefore, consists of 150-180 hours of work by the student. Some of these hours are face-to-face time, when students work in the presence of the teacher (10 hours per credit is a typical value in Spain), while the rest is undertaken by students themselves in order to complete the studies required by the subject. It is the responsibility of teachers to determine when and how much work that students should do outside of the classroom, which should ideally be evenly distributed throughout the course (P5).

• Poor relationships among classmates also constitute a factor in demotivation. While this is an issue that in most cases is not entirely in the hands of teachers, encouraging good peer relationships (based on cooperation rather than competition) helps to avoid demotivation (P2).

3.6. Maintain student attention (P1, P2, P3, P4, P5, P6, P7)

Lectures require voluntary attention, while active learning (P3) requires involuntary attention. At present, some students find it difficult to hold their voluntary attention, which makes traditional lectures less effective with current generations of students than with previous generations.
Once motivation has been achieved and attention has been awakened, the teacher must know how to maintain them. The existence of a maximum fixed time to maintain the focus of attention has yet to be determined [21]. It is thought that attention time may differ, depending on the material treated. In any case, performing 50 activities, each consisting of 10 minutes, is preferable to doing 10 activities lasting 50 minutes. In the case of lectures, a 50-minute exposure session should not be carried out without some interruptions or changes. Teachers can maintain attention by “interrupting” a 50-minute activity every 10-15 minutes, introducing the projection of an image (in the case of speech-type lectures) or recounting an anecdote to illustrate a case that prompts debate, a joke, etc. The value of the attention times is somewhat difficult to assess, since the focus of attention depends on the age of the student, the teacher's teaching capacity, the interest of the subject and the prior training of both the learner and the teacher [21]. In any case, the teacher should take into account that the information is stored in the short-term memory for only a few seconds, and it is necessary to give the student time for this information to pass to the long-term memory; otherwise, the short-term memory becomes saturated and the information is lost.

What can the teacher do to fix the learning in place? Many university curricula include separate problem and theory activities. This constitutes good organization from the point of view of efficiency, in terms of resource optimization (theory classes with many students enrolled and few teachers, and problem classes with fewer students enrolled and more teacher requirements), but is not recommendable from the point of view of learning, because theory classes tend to be very formal and as such it is very difficult to maintain student attention. Getting voluntary attention requires practice and training, so activities demanding this kind of attention must be performed repeatedly.

A better strategy consists in addressing some problems during the classroom time, just after the theory (P3), although this strategy allows development of only the lowest domain levels of the learning taxonomy. The problems corresponding to the application domain level must be prepared previously (at home) by the students (P7), and can be developed in groups later in the classroom (P2, P3, P5). In this case, the teacher acts as moderator (P1, P4, P6), as proposed by Álvarez, Fernández, Llosa and Sánchez [54]. The strategy of intercalating short problems in lectures improves student learning (P1, P3, P4). In one-hour lectures, a brief activity of five minutes (for example, solving a short problem) can be interspersed every ten to fifteen minutes.

### 3.7. Explain the most important points at the beginning and end of the class (P2, P3, P4, P5, P7)

This strategy is based on the serial-position effect discovered by Ebbinghaus. According to the serial-position effect, the accuracy of recall of the items on a list depends on their position on the list. People tend to remember better the first and last items on a list. The effect of remembering the first items better is known as primacy, while the effect of remembering the last items better is known as recency.

The effect of primacy may be due to the fact that the first items on a list are stored more effectively in the long-term memory, because the brain devotes more time to remembering them (the first item must be tested against the second, the first two elements against the third, and so on). This effect may be used in a lecture. If teachers explain the key concepts at the beginning of the class, and make reference to these concepts throughout the class, students spend more time remembering and relating these concepts. The primacy effect diminishes when the items on the list are scanned very quickly, thereby suggesting that it is necessary to allow time for the brain to work on them. Time should therefore be devoted throughout the class to enabling students to understand and assimilate the concepts introduced at the beginning. Teachers should not limit themselves merely to enunciating the concepts.

Starting a class by explaining the key concepts is a methodology opposed to that used by many teachers who, when explaining a concept, follow a long reasoning process throughout the rest of the time and leave the crux of the matter until the end [55]. By employing the aforementioned methodology, however, teachers can capitalize on another of the characteristics of the serial-position effect: the effect of recency. The recency effect occurs because the items on the recall list are still present in the working memory when their recovery is required. This effect diminishes when any interference occurs, since such interference may occupy the working memory, thereby erasing the last items in the series. It has been shown that, if the information is retrieved immediately after memorization, the recency effect is constant regardless of the

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1 For example, the levels of knowledge and understanding if Bloom's taxonomy is used [53].
length of the list 56]. The recency effect may therefore be used in a lecture, since it will occur regardless of how long the class may last.

Thus, the strategy for making the most of the serial-position effect in a lecture is as follows:

1. Begin the class by explaining the key concept to be addressed. This also favours student motivation.
2. Give the students a few minutes to reflect on the concept. This can be done, for example, by explaining a direct application of the concept, asking students to find real examples of its application, and asking them to do an exercise based on the direct application of the concept, etc. (P2, P3, P4, P7).
3. Develop the concept in class. Development may involve describing the historical evolution leading to the discovery or invention of the concept, the mathematical demonstration of the validity of the concept, the actual applications of the concept, etc. (P5).
4. Conclude the class by going over the concept again and asking the students to summarize the most important points. This is a vital exercise, since evocation is required for the recency effect to occur (P2, P3, P4, P7).

3.8. Help students to memorize the concepts (P1, P2, P3, P4)

As Ebbinghaus demonstrated more than a century ago, repetition is essential in order for students to memorize what they have to learn. Teachers should encourage the practice of memory, since the attempt to remember has an impact on learning. For example, towards the end of the class teachers can ask students questions about the key concepts they have been studying (P1). According to Dunlosky, Rawson, Marsh, Nathan, and Willingham [57], this technique yields better results than the exposition of mental or conceptual maps on the blackboard or projecting them onto a screen. To help memorization, the teacher must continuously provide students with feedback (P4), repeat points without being boring (using different points of view), relate what is being explained with other concepts (even with concepts unrelated to the subject, to awaken curiosity), encourage students to make mental and conceptual maps (by themselves), or use an initial index and do a final review, as discussed in the previous section.

Memorizing concepts serves no purpose if the student does not understand them. Learning must be developed in a contextualized environment, because memory is made up of multiple connection patterns, and when a pattern is activated “the memory” ensues. Each new memory alters the existing connections and enables new connections to be added. The broader the connection network and the less energy required to activate the connections, the easier it is to access the memories.

To facilitate understanding, minor contextualized activities can be designed during the class to enable students to develop the lowest levels of the learning taxonomy. These activities may also break the monotony of a linear discourse by the teacher, and therefore facilitate the transfer of information in the student’s short-term memory to the hippocampus, and then to the long-term memory. These activities should be oriented to awakening emotions in the students in order to fix learning more efficiently. Doing these activities not only helps the understanding of the concepts, but also facilitates their memorization, thanks to which they encourage the practice of memory. Some activities of this type are as follows:

- Small problems regarding the direct application of the concept. Individual resolution by the student. The teacher presents the solution and asks if anyone has any doubts (P1, P3, P4).
- The teacher relates the newly developed concept to other concepts already known to students, and asks a question involving all the concepts simultaneously. Students discuss in pairs and draw up a solution that is discussed later with the rest of the group (P1, P2, P3, P4).
- The teacher poses a small problem that the students must solve in time for the next class, which begins with a review of the concepts seen in the previous class, and a student is asked to solve the problem on the blackboard and explain it (P1, P3, P4).
- The teacher asks a question to spark a debate on the concept being studied (P3).
- Some news related to the concept is discussed in the classroom, and students are given 10 minutes to comment on this news in groups of three. Finally, the conclusions of the different groups are shared. (P2, P3).
- Some students are asked to explain the concept under study to the rest of the class, commenting on some examples of application (P3).
Some of these activities may be conducted using the traditional method of verbal interaction between teacher and students, but they are more effective (and take less time) if a system based on clickers (response-ware systems) such as kahoot (https://kahoot.com) or socrative (https://socrative.com) is employed. Moreover, students find the use of technology in the classroom attractive, so the use of a computer, tablet or mobile in the classroom increases their motivation and attention.

3.9. The power of good questions (P1, P2, P3, P4, P6, P7)

Broadly speaking, metacognition involves the analysis of the learning process itself, and brings into play various cognitive strategies such as planning, generation of alternative solutions, analysis, synthesis and evaluation of processes whenever new challenges arise [58]. Fostering metacognition with the didactic proposals presented herein facilitates meaningful learning.

A good strategy for stimulating metacognition (ability to self-regulate learning processes, P7), is for the teacher to ask questions during class (P1, P3, P4, P6) [1, 55]. Asking students essential questions is very important for their learning. Teachers should give them enough time to think about the questions before answering them, even allowing them to discuss the answers as a group (P2, P3, P4, P6). This is a good way of introducing a pause into the class every ten or fifteen minutes.

As mentioned above, well-chosen questions are useful to help memorize concepts. A good question not only guides students in the direction in which they should think; it also forces them to reflect on what they have just learned, and build knowledge by relating it to what they already know.

A good question should include a reference to something already known by the students, something they can relate to the new concept they are studying but whose a priori relationship had not occurred to them. This relationship between the new and the already known should be calculated to surprise the students (because surprise activates the mechanism of curiosity, and therefore helps students to achieve intrinsic motivation).

3.10. Use specific examples to understand complex ideas (P7).

In general, the brain learns from what it understands by moving from the concrete to the abstract [21]. However, some students learn better in reverse; that is, by understanding abstractions first and then seeing concrete examples. This is a consequence of different learning styles (P7), as will be mentioned in Section 3.12.

Many teachers start by explaining the theories from an abstract point of view, and only then provide actual examples of application. For most individuals, learning by understanding how a real example works and then trying to abstract the underlying theory from the example is more effective. Teachers should therefore always use specific examples for the understanding of complex ideas and approach the general rule from particular cases [59].

Nevertheless, teachers must bear in mind that some students (the minority) learn best by starting from abstract concepts, so they should take care to be very precise and provide full explanations when explaining concepts in an abstract way, rather than expecting all students to be capable of exercising abstract thought unaided on the basis of concrete facts. Using specific examples to understand complex ideas helps to awaken students' motivation and maintain their attention.

3.11. Establish a good understanding with the students (P1, P6, P7)

The relation between teachers and students is very important (P1) [60]. Many teachers tend to categorize students (for example, by distinguishing between good and bad students) and treat them according to that categorization. It is also very common for students to categorize themselves ("I'm bad at mathematics"), which is highly inappropriate behaviour. Students who believe they are unfit for math will probably make no effort to understand the subject, and eventually will fail. On the other hand, those who believe they are good at math will make an effort to understand even what is difficult for them. This is an important factor to take into account, because the exercise of effort generates a growth mindset [61], which is conducive to learning. This growth mindset is the same as that used by athletes when they “visualize” the challenges they
seek to overcome. Ptak, Schnider, and Fellrath [62] showed that thinking about doing something has almost the same effect on the brain as doing it. Learning to play the piano causes growth in the same areas of the brain as simply imagining that you are touching the keys. Teachers should strive to convey that growth mindset to students [63] rather than prejudging their ability. Rejecting categorization means accepting students as they are and encouraging them to get the best out of themselves and develop their full potential (P6). It implies respect for their different talents and ways of learning (P7), as well as an understanding that all the students are different and can attain their goals in different ways and over different spans of time. Establishing a good understanding with students contributes to maintaining their motivation in class.

3.12. Use Universal Design for Learning (P7)

The learning styles of students in any classroom are usually very diverse. Conceptually, learning styles are understood as personal variables that are midway between intelligence, cognitive styles and personality. These learning styles account for the different ways that students approach, plan and respond to the demands of their own learning. Each student processes information in a different way: some students are more skilled in the management of verbal information and others in visual information; some learn by moving from the concrete to the abstract, while others do it the other way around. Some authors define the learning style of an individual on the basis of his or her behaviour in accordance with a set of learning dimensions [64].

Teachers have the responsibility to teach using a variety of methods suitable for the encouragement of learning for all their students. This is essential for maintaining the motivation and attention of most students and for guaranteeing understanding of the contents and promoting meaningful learning. Reliance on only one methodology may result in the motivation of a few students, but the rest will lose motivation. Thus, teachers must diversify the teaching methodologies they use and combine them if necessary. One way to respect different learning styles (P7), for example, is to prepare the slides to be shown in class in a way that suits different learning styles. Mayer and Anderson [65] proposed what they called "dual coding" for slides, which consisted of combining images and texts to respect the different learning styles. This idea is currently included in what is known as Universal Design for Learning [66]. According to this paradigm, the slides should combine images, texts and videos alternated with the explanations, the questions and the examples, as well as the various strategies explained.

The Universal Design for Learning (UDL) is "an educational framework based on research in the learning sciences, including cognitive neuroscience that guides the development of flexible learning environments that can accommodate individual learning differences" [66]. The UDL is a way to organize teaching and learning to help provide all students with the same opportunities of success. The UDL is flexible about the ways in which students access the material, express their interest in it and demonstrate what they know. Drawing up a lesson plan in accordance with UDL helps all students, but can be particularly beneficial for those who experience learning and attention difficulties.

The UDL should be applied to both class planning and assessments, and is based on three fundamental principles:

- **Representation:** The information must be offered in more than one format. For example, textbooks are very visual. Providing complementary material in audio and video format, and doing practical learning, enables all students with the opportunity to access material in the way that best fits their learning strengths.
- **Action and expression:** The UDL allows students to interact with the material and show what they have learned in several ways. For example, they may choose between taking a written exam, giving an oral presentation or carrying out a team project.
- **Participation:** The UDL encourages teachers to look for different ways to motivate students. Allowing students to make their own decisions about their learning, and assigning tasks that students consider important for their lives, are just two examples of how teachers can maintain student motivation. Other strategies to encourage participation include the use of gamification techniques in class (which are hardly compatible with a lecture).

4. Discussion
The twelve tips presented in Section 3 are based on the human learning process described in Section 2. Eleven tips promote motivation, eight are designed to activate or maintain attention, and four help the memorization process. Despite the fact that the twelve tips involve emotions, nine of them are firmly focused on emphasizing that learning is associated with a positive emotional experience. Table 1 shows the relationship between the twelve tips, emotions and the three main phases of learning.

Table 1: Relationship between the twelve tips and the three main learning phases, emotions, and the seven principles of quality teaching.

<table>
<thead>
<tr>
<th>Tip</th>
<th>Motivation</th>
<th>Attention</th>
<th>Emotions</th>
<th>Memorization</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>P7</th>
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<tbody>
<tr>
<td>Enter the class with a smile and energy</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<td>Students know and interact with each</td>
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<td>Causing surprise in students</td>
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<td>Tell interesting good stories</td>
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<td>Maintain student motivation (do not</td>
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<td>Maintain student attention</td>
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<td>Most important points at the beginning</td>
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<tr>
<td>Help students to memorize the concepts</td>
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<td>Ask good questions</td>
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<td>Specific examples to understand complex</td>
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<td>Establish a good understanding with the</td>
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<td>Use Universal Design for Learning</td>
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</tbody>
</table>

Some of the tips develop the three phases of learning (Help students to memorize the concepts, and Ask good questions), so they may be regarded as being the most complete. However, not all indicators contribute in the same way to the learning phases indicated in Table 1. In this work, we have chosen to identify whether
a tip contributes or not to each of the phases. The X's in the table indicate that a contribution exists, but we did not measure the size of the contribution. Although a range could be established for the contribution of each tip to each phase of learning, the final result of the said contribution depends entirely on how teachers implement the tip in their classes. This study is very interesting, but is outside the scope of this paper, and will form part of the authors' future work.

Table 1 also shows the relationship of each of the tips with the seven principles of quality teaching set forth by Chickering and Gamson [26]. As can be seen in the table, all tips contribute to at least one of the principles, and two of them (Maintain student motivation -do not demotivate-, Maintain student attention) contribute to all seven. If we analyse the table from the point of view of the seven principles of quality teaching, the principle promoted by more tips is P1 (Encourage contact between teachers and students), which is developed in nine of the tips, closely followed by the principles P2 (Encourage cooperation among students) and P7 (Respect different talents and ways of learning), which are developed in seven of the tips. On the other hand, the least developed principles are P5 (Dedicate time to the most relevant tasks) and P6 (Communicate high expectations to students), which are developed in only four of the twelve tips.

Engineering teaching should take into account the three phases of learning described in Section 2. Any teaching-learning method should be designed from the point of view of the functioning of the human brain rather than regarding the brain as a black box in which the Knowledge can be inserted in any order and in any way. The human brain is the most complex mechanism that we know and, if we want to optimize its operation, as teachers we must understand how the learning process of our students works, and design our teaching strategies to optimize this operation accordingly. As demonstrated in this study, neuroeducation is a novel research topic that is still in its early stages. Novel ideas must be investigated before they become mainstream. The interconnection of all research works related to neuroeducation can generate benefits for students and teaching staff alike. In this work, we have focused on detailing some strategies (the twelve tips) for developing the three main phases of learning in the lectures. One may believe that these strategies are only suitable for promoting learning of the specific competencies of the degree. However, the twelve tips can also be used for developing generic competencies and values. The areas of the brain involved in the learning of values do not finish maturing until 23-26 years of age [21]. Despite what some teachers may believe, this means that the university should continue training in values that are often overlooked, such as punctuality, responsibility, fulfillment of commitments, self-sufficiency, self-control, the emotional domain of language (tone, voice modulation, etc.), ethics and its basic principles, and respect for the personal space of others. These values are essential for any human being to become integrated into 21st century society.

Familiarity with teaching practices that can be used to improve the teaching-learning process is just as important as identifying the factors that hinder this process. Once these factors are known, and the functioning of the human brain is also known, it is possible to design teaching strategies that promote the teaching-learning process while avoiding the impediments to this process. Hattie [67, 68] published an analysis of 800 meta-studies carried out on 300 million students to determine the effect size [69] of various variables, such as the influence of programs, methodologies, techniques, and even situations or personal conditions on learning. He classified the effect size (d) with an absolute value between 0.0 and 2.0. The value of d can be positive or negative, indicating that the effect is detrimental to learning. From the value d=0.40, the intervention is considered effective, while if it exceeds d = 0.60 it is regarded as being at the level of excellence. The most important factors for learning, related to lectures, are Boredom (d=−0.49) and Student expectations (d=1.44). Boredom is related to motivation, and motivation is a key element for facilitating the focus of student attention, thereby enhancing the learning process. Boredom may account for why students present practically flat brain activity when they attend a lecture [5]. Teachers must therefore avoid student boredom in class at all costs [1, 55]. Student expectation, on the other hand, corresponds directly to Chickering and Gamson’s P6 principle. The students’ own beliefs about their academic performance, often based on previous negative experiences, have an extraordinary influence on their learning. This is closely related to the growth mindset mentioned in Section 3.11. Hattie's study is an empirical study, but it would be interesting to know the neuroscientific basis supporting it in order to define the teaching strategies that reinforce improvement in learning and avoid the factors that hinder it.

This study has some limitations. The twelve proposed tips have been extracted from the authors' own experience and from an extensive bibliographic review of neuroscientific and education-related reading. Although all the tips have a proven scientific basis, it is necessary to conduct experimental work to determine how they affect the learning process and whether they really improve it and lead to better results. Table 1 is a Boolean table that only identifies whether or not the tip contributes to each of the phases, to
the development of emotions and to each of the seven principles of good practice. It is necessary to quantify this contribution by carrying out specific experiments to measure the effect size of each variable.

The twelve tips presented in this paper constitute just one example of how the main phases of learning can be addressed in a lecture. The authors consider that these twelve tips are a representative sample of good teaching practices. Furthermore, it is necessary to provide similar guidelines to help improve the learning process when using other teaching-learning strategies, such as PBL, flipped classroom, or learning-service. This is future work that the authors plan to tackle.

5. Conclusions

In this paper, we set out some of the factors and strategies that, according to neuroscience, should be considered by teachers when giving a lecture. The paper reviews the principles of learning in the light of the latest discoveries in neuroscience, and describes how each of the three main phases of learning function: motivation, attention and memorization. These strategies are related to the seven principles of teaching quality.

It is concluded that some of the strategies available to teachers in a lecture in order to improve student learning outcomes are: "Entering the classroom with a smile and with energy"; "ensuring that students get to know each other and interact with each other from the first day"; "provoking surprise in the students"; "telling stories during the class"; "keeping the student's motivation and not discouraging"; "keeping the student's attention"; "explaining the most important things at the beginning and end of the class"; "help students to memorize concepts", "ask students essential questions"; "use specific examples to comprehend complex ideas"; "establish good understanding with students", and "use Universal Design for Learning".

The research that forms the basis of this work should be expanded in order to include greater practical implications. On the one hand, it is necessary to draw up a list of tips aimed at achieving successful learning within the framework of other teaching-learning strategies, such as PBL, flipped classroom or service-learning, always within the framework of neuroscience and neuroeducation. On the other hand, it is also necessary to investigate the real effectiveness of putting into practice the twelve tips presented in this paper. Specific research work is required on each of the tips in order to assess the extent to which they contribute to promoting each of the three phases of the learning process analysed in this paper. This research must be carried out jointly by engineering professors and experts in pedagogy, psychology and neuroscience. Only by combining these four groups of scientists will results be obtained that can be applied to engineering education, and by extension to the education of other disciplines and educational stages in human life.

Finally, advances in neuroeducation should be not be confined to improving the teaching strategies employed by teachers in their subjects. The designers of curricula and those in charge of designing and conducting the academic management of the degrees must also take into account the functioning of the human brain when carrying out their work. Only in this way will they be able to maximize student learning, since the scope of teachers is limited to what they are able to do in class. Their actions necessarily affect the work that students undertake in all the subjects they study simultaneously, and therefore affect the work undertaken by other teachers.

This paper constitutes only a first step for teachers to improve their lectures using the knowledge provided by neuroscience because, as Leslie Hart stated, teaching (educating) without a knowledge of neuroscience is akin to designing a glove without ever having seen a hand.

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References


Figure legends

Fig. 1. Most relevant factors in the learning process
Fig. 2. The human memory system

Table legends

Table 1 Relationship between the twelve tips and the three main learning phases, emotions, and the seven principles of quality teaching.

Biographies

Fermín Sánchez-Carracedo received the B.S. in computer science in 1987 and the Ph.D. in computer science in 1996 at Universitat Politècnica de Catalunya (UPC-BarcelonaTech). His research areas include computer architecture, innovation in education and Education for Sustainable Development. Teacher of the Postgraduate Program ‘University Teaching in Science, Technology, Engineering and Mathematics (STEM)’ of the UPC-BarcelonaTech since 2017, and teacher of the Master Degree in ‘Innovative Learning Processes’ of the Universidad de Guadalajara (Mexico) since 2017. He was a course instructor at the UOC (1997-2010) and Vice-Dean of Innovation at the Barcelona School of Informatics-FIB (2007 -2013). Since July 2013, he has been Deputy of Innovation at the FIB. He has more than one hundred fifty publications related to his research topics. Dr. Sánchez-Carracedo is Member of the BCN-SEER, group (https://bcn-seer.upc.edu/en) which coordinates the track ‘Education for Sustainable Development in Engineering’. Is the Main researcher of the EDINSOST project. and is the manager of the UPC-Reutilitza program. He was a member of the JENUI Steering Committee from September 2006 to July 2015 and he was its Program chair from 2011 to 2013. He has been a member of the NGO TxT (Technology for Everybody) since 2004 and is the Chair since 2017. Dr. Sánchez awards include the 2017 AENUI award for teaching quality and innovation; the UPC Award for Social Commitment 2019, cooperation modality, as manager of the UPC-Reutilitza program; and the UPC Award for quality teaching 2020. More information about Fermín Sánchez-Carracedo research: https://futur.upc.edu/FerminSanchezCarracedo.

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She combines her daily clinical practice with university teaching and research. She is an associate professor at the UAB Department of Clinical Psychology and Health, and also collaborates as a teacher in master and postgraduate programmes at different Spanish universities. She belongs to the Factors of Vulnerability in Psychopathology research group. She is the author of various research papers in the field of Psychopathology and behavioural problems.

Alejandra Barba-Vargas. Graduate in Psychology (2018) and currently doing a Master’s in Innovative Processes in Learning, both courses being imparted at the Universidad de Guadalajara, Mexico (UDG). She teaches “Human Resource” courses as part of the Agro-Industrial Degree at the UDG. Her main research line is focused on Educational Innovation Methodologies. Since 2016, she has been working at the Centro Universitario de los Altos (CUAltos), regional campus of the UDG. She has been an assessor of research projects of the University Research Day Sessions at the CUAltos, coordinator of the national and international reaccreditation processes in Psychology and Law Degree courses, and a member of the organizing committees of different academic activities at CUAltos, which include entrance examinations, day sessions, colloquia, knowledge marathons, forums and cultural programmes. In 2018, she was distinguished by the Centro Nacional de Evaluación para la Educación Superior de México (Mexican National Evaluation Centre for Higher Education) with a qualification of outstanding in her Degree in Psychology. She completed a stay at the Universitat Politècnica de Catalunya, Barcelona, Spain, in November 2018, participated as speaker at the Guadalajara Educational Forum, and conducted workshops for personnel belonging to hospital authorities. In 2109, she presented a paper at the XXV Jornadas sobre la Enseñanza Universitaria de la Informática (JENUI - 25th) in Murcia, Spain, and has also given thematic talks in the fields of psychology and education on regional radio stations and social and television networks in Mexico.