

# Modern technologies and concepts for Education

## III – innovative methodologies for engineering education

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### Annotation

This paper considers the current role of the university lecturer in engineering education. It briefly describes how to be a good teacher and the elements that facilitate this task. A broad guide is offered on how to manage class dynamics given the new teaching challenges. The lecturer's relationship with the new methodologies that impact on the training of engineers is discussed. Approaches are examined for incorporating these new methodologies into classes in an innovative way through student-centred teaching techniques. Finally, the emergence of online training as a new educational format is analysed and practical recommendations are made.

### Objectives

Identify the relevant aspects of teaching in the current context of engineering degrees.

Identify the conditions for learner-centred learning.

Establish a teaching strategy that is structured using Bloom's taxonomy.

Consider different ways of learning with Kolb's model, and its application when planning teaching sessions.

Consider learning models focused on active methodologies.

Establish the characteristics of meaningful learning and differentiate active methodologies according to Horváth's topography.

Differentiate between organisational modalities, teaching methods, and key teaching techniques to establish an innovative and flexible teaching methodology.

Understand the main aspects of virtual teaching and guidelines for effective application.

### Keywords

Learning models, significant knowledge, active teaching methodology, teaching methods, project based learning, learning contract, virtual mode.

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## **Literature**

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## CHAPTER 1

# Introduction

Is teaching an art? Many people would consider that it is an art, but this would imply that only artists can be teachers. However, many of us who have the pleasure of teaching do not consider ourselves to be artists. Without further exploring the question, neither in form nor in substance, all art involves technique – and without a minimum base of knowledge it is implausible that the adjective of artist can be applied.

### DEFINITION

Teaching is learned and teachers are made rather than born. Teaching requires a combination of abilities including knowledge, skills, and attitudes (Llorens, Llinàs, Sabaté, 2009), that enable this key task in the advanced world to be carried out.

The main motivation of every teacher lies in the desire for others to learn and to see that students are taking ownership of the learning objectives we have set for them.

In university engineering education, this motivation has a broader component. We are generating the talent that will create economic and social growth and we must ensure the best professionals take up the challenge.

In the following chapters we will summarise the key aspects for being good teachers, as well as the elements of the environment that facilitate and improve the teaching task and that serve as a guide for a broad evaluation of how to manage classroom dynamics. And we will do so by evaluating their relationship with the new teaching methodologies that impact on the education of engineers. We will also analyse the emergence of online training as an educational format.

## 1.1 Teaching engineering

### DEFINITION

The European Higher Education Area sets the architectural framework for degrees and educational practice in European universities.

We have just survived a pandemic that has confined virtually the entire European population to their homes. It has suddenly changed the way we organise schools, colleges, and universities. Covid-19 has changed the educational context in one of the most urgent and drastic ways we have ever seen (at least for those of us fortunate enough not to have lived through other disasters, natural or military, which would have had similar consequences). The fact is that the real world context essentially determines the way in which the teaching-learning process is exercised. Sometimes it can be positive and sometimes negative; the teacher's responsibility is always to adapt to the context so that it is as favourable as possible for the intellectual and professional growth of our students. A good teacher must be flexible to the environment and adapt to it in the best way possible. Because context conditions the functioning of the classroom, but also predisposes students to one situation or another, it is important to detect the effect on them.

For these reasons, it seems essential to have a good reference point and a defined methodology so that the preparation of the teaching guide, class planning, learning objectives – and the forms of monitoring and evaluation must always be well designed and understood by the students. The teacher-student relationship generates an important channel of communication and relationship and we must protect it.

### DEFINITION

The main function of the university is the triple action of teaching, research, and knowledge transfer.

Work and social changes, especially relevant in the field of the engineering profession, are changing curricula and learning objectives. A call to adapt to the needs of the market may not be a particularly desirable milestone among some segments of university management, but it is widely shared that new societal needs must be taken into consideration.

Since the talent of graduates is a crucial contribution to the improvement and development of society, nobody doubts the importance of higher education and it is recognised as a right and a duty of every state towards its citizens. As a result, national budgets include large investments to support and improve the educational system in general and the university system in particular. This requires compliance with the quality standards that allow access to institutional, national, and international accreditation, as well as demonstrating compliance with the competitiveness objectives required in degree courses.

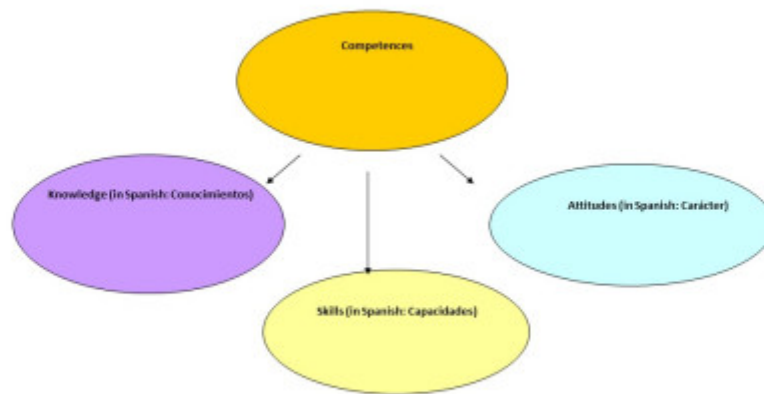


Fig. 1. The 4 C's model. Source: Llorens, Llinàs, Sabaté (2009).

[Interaktivní prvek](#)

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## 1.2 The learning focus

It is not possible to establish a set of contributions regarding new teaching methodologies for engineering studies without first approaching what we expect from the engineers of tomorrow. A relevant improvement of the new educational approach, namely the Bologna process, has put the focus of learning on the student – moving from a teacher-centred model to a student-centred model.

### DEFINITION

The Bologna declaration, also known as the starting point of the European Higher Education Area, set in 1999 that new degrees should promote the employability of European citizens as one of the objectives.

One of the topics of the current debate on science and technology is to determine which aspects have shaped modern and traditional societies. Both scientific and technological advances have radically changed humanity's relationship with nature and the interaction between living things. Engineering has even influenced the mentality of humankind. Today's society is no longer captive to the conditions of the past and present and is oriented towards the future. Science has become a key factor in social development in virtually all areas of society.

In the new environment of higher education in Europe, the future engineer develops his or her activity in the information and communication society and therefore in the knowledge society, and so it is essential to instil the abilities that contribute to a harmonious development of this society.

The training that engineering students receive is of vital importance as it will determine the abilities that they eventually acquire. The learning protagonist is not the teacher, but the student, and this fact is relevant in how we should approach teaching. Consequently, once we have specified what these abilities should be (an area that is outside the scope of this work) we must design a learning methodology that favours the acquisition of these abilities. We will analyse various strategies in the following chapters.

[Interaktivní prvek](#)

## CHAPTER 2

# New teaching methodologies

We can define teaching methods or strategies as the set of procedures based on teaching techniques that aim to achieve the learning objectives.

### DEFINITION

The teaching technique is the resource used by the teacher to achieve the purposes set out in the method or strategy and is made up of various actions or activities.

Examples of teaching techniques include: project-based learning; learning-by-doing; learning contract; problem-based learning; case method; master class; business games and simulations; and the question technique.

In choosing the method and techniques to be used, the following criteria must be recalled: validity; comprehensibility; variety; appropriateness; relevance or significance; clarity of intention; knowledge of procedures; and the appropriate insertion of exercises in class planning.

It should not be forgotten that training actions must aim to achieve learning objectives and that the learning process is quantified in evaluations. It is necessary to structure education in levels and for this task we can use Bloom's Taxonomy.

### DEFINITION

Bloom's Taxonomy (Bloom, 1979) classifies the objectives of education hierarchically by levels and differentiates between cognitive, affective, or psychomotor levels.

In the affective dimension described in Bloom's taxonomy we have the objectives that correspond to emotional reactions, attitudes, and feelings. It is structured in five levels: reception; response; appraisal; organisation; and characterisation. In the cognitive dimension, the objectives correspond to knowledge and understanding and are structured in six levels: knowledge; comprehension; application; analysis; synthesis; and evaluation. In the psychomotor dimension, we have five levels: imitation; manipulation; precision; control; automation and creativity.



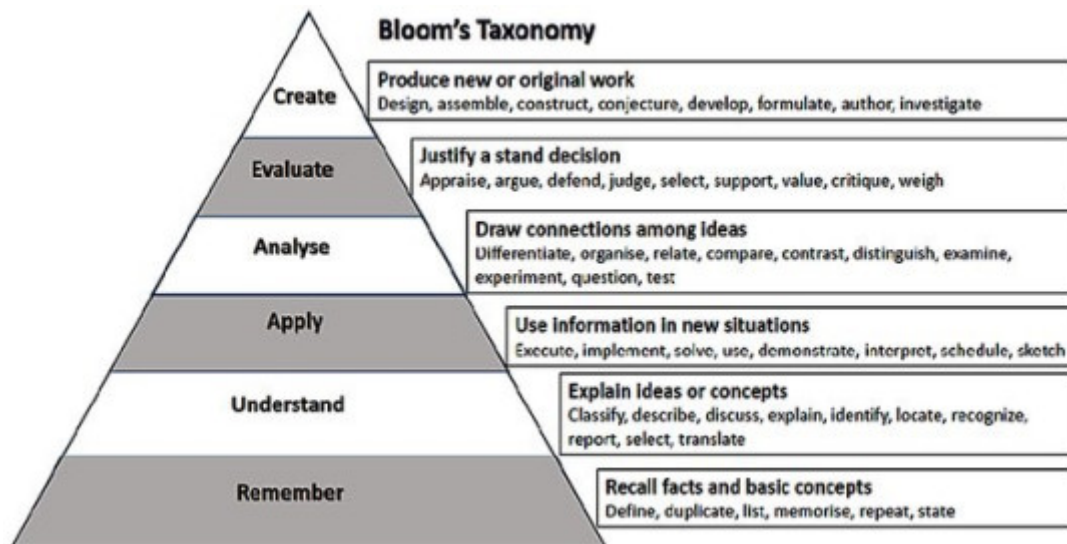


Fig. 2. Bloom's Taxonomy cognitive level.

Not all cognitive actions have the same level of complexity, for example, remembering a certain piece of information is not the same as analysing or evaluating it. This taxonomy makes it possible to create a simple and effective hierarchy of educational objectives, and this has formed part of teaching strategies since its formulation by Benjamin Bloom in 1956. Bloom offers us the compass to avoid getting lost in the teaching profession.

This tool is especially useful for writing learning objectives.

### DEFINITION

A learning objective is a statement that clearly expresses what the learner should demonstrate at the end of a stage or learning period.

Consequently, the teaching activities that pursue these statements must be observable, measurable, and assessable, and teachers can use the verbs employed in Bloom's taxonomy to write them (indicating what, how, with what, and why).

In the wording of the abilities that engineering student must acquire at the end of each subject and stage, we can use a verb from the verb table in Bloom's taxonomy, to identify how to measure, and finally, describe the objective.

[Interaktivní prvek](#)

## 2.1 Ways of learning

### DEFINITION

Kolb defines four types of students whose learning styles vary according to the way they perceive and process information. They are divergent, convergent, assimilative, and analytical/accommodative.

Kolb's learning model is now one of the best known and most widely applied learning style theories. According to this model, 'convergent' learners possess dominant skills in the areas of abstraction, conceptualisation, and experimentation, and are particularly good at the practical application of ideas. The dominant skills of 'divergent' students are seen in areas of experience and reflective observation (essentially the opposite of convergent students) and they tend to be emotional and creative. Assimilative students are adept in areas of abstraction, conceptualisation, and reflective observation; and so understanding and creating theoretical models may be one of their greatest strengths. However, they tend to be more interested in abstract ideas and not so much in people. They are not generally interested in the practical applications of theories. Finally, 'accommodators' have their strengths in specific experience and active experimentation. They enjoy setting up experiments and executing plans in the real world.

In the same classroom we must train future engineers who may respond differently in accordance with the above definition. We have tended to develop technical degrees that – at least in the initial stages – are based on abstract concepts and assimilation. However, the engineering profession is more inclined towards technical fields or action-oriented jobs and so students of a more accommodating typology should predominate.

For these reasons, it seems essential to have an open teaching approach that does not guide the contents in a rigid and permanent way. Such an approach must be capable of adapting to the diverse ways of learning and so relate each type of student with one of the teaching methodologies – depending on the effectiveness that we observe in the learning evaluations.

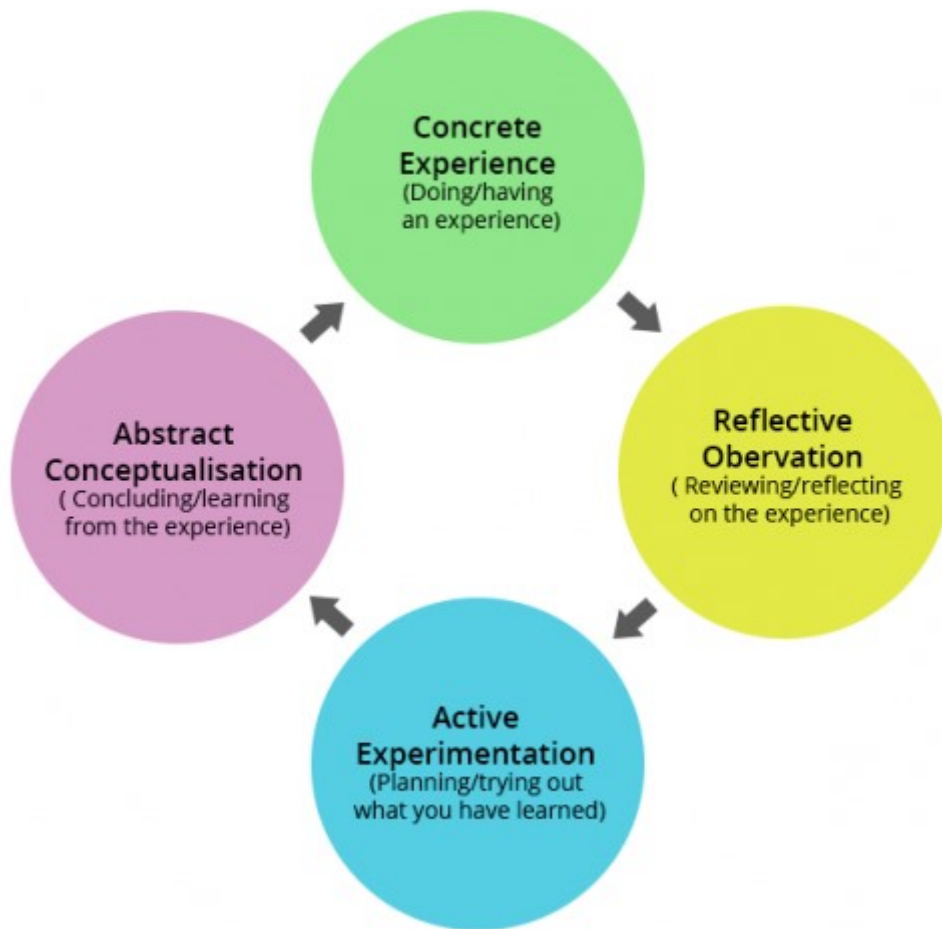


Fig. 3. Learning styles. Source: D.A. Kolb (1984).

## 2.2 Learning models

### DEFINITION

There are a variety of learning models: conditioned reaction; psychoanalysis; behaviourism, the discovery path; and constructivism.

Let's look at each. The conditioned reaction model, whose main author is Pavlov, argues that there must be a cause-effect relationship for learning to happen. The model supposes that learning is based on repetition followed by rewards or punishments.

Psychoanalysis, devised by Sigmund Freud, states that the affective dimension of people must be considered as this directly influences the relationships between students, as well as student-teacher relationships. Methods should be used to enhance these relationships – such as tutorials or group work.

Behaviourism states that the two basic principles for learning are individual motivation and the consolidation of concepts through repetition.

Dewey developed the discovery path, which bases learning on the solution of problems so that individuals themselves discover and identify the following stages: delimiting the problem; analysis of workable solutions; and experimental verification.

Finally, constructivism (according to Piaget, one of its pioneers) states that learning is a process of knowledge construction. Learning takes place through the internal reconstruction of information.

[Interaktivní prvek](#)

## 2.3 Meaningful learning and active methodologies

Constructivism is a theoretical framework that includes nearly all the previous currents of the learning process. According to the constructivist paradigm, knowledge is not transmitted because each individual constructs their own learning.

According to Ausubel (1963), one of the most recognised representatives of constructivism, knowledge is usually transmitted by an expository process; however, the construction of knowledge requires reflection and internalisation for its application. This approach is called meaningful knowledge.

Meaningful knowledge is also:

- built under an active work of interpretation and modelling of experience and is transferred to situations and new contexts in such a way that knowledge is the interpretation of experience and an ability to transfer.
- demanding of active work on the solid structuring concepts – and here we understand knowledge as models or mental structures.
- based on interaction and social negotiation of interpretations and models, whereby we understand knowledge as a socially constructed meaning.

The central axiom of the constructivist paradigm is that meaningful learning is not reception but construction. It is an individual and non-transferable constructive process that is driven by personal involvement in the task, an involvement enhanced by the perceived need and meaning of what is being done, as well as independence and decision-making ability.

However, the observations of Cannon, Kapelis and Newble (2000) should be noted: there can be no such thing as totally passive learning. In fact, it is preferable to refer to learner-centred teaching methodologies because all teaching methodologies are active to a greater or lesser degree.

### DEFINITION

We understand active (or learner-centred) teaching methodologies as those that emphasise the participation of the learner in the learning process (Braxton, Milem, and Shaw Sullivan, 2000).

Non-active forms of learning are oriented towards knowledge absorption and memorisation. Active forms of learning seek to introduce intellectual processes that improve and extend the quality of learning (Osborne and Wittrock, 1989).

Kolb defended active and cooperative learning as being more natural and familiar than more traditional teaching methods. John Dewey also based much of his contribution in the field of teaching to the defence of active learning or practice, as opposed to the then dominant passive techniques.

An interesting current scheme to identify the variety of active teaching methodologies is the so-called Horváth topography (Horváth, Wiersma, Duhovnik & Stroud, 2004). This model, shown in Figure 4, classifies active methodologies according to whether they focus on the individual, the group, or the

community in general – and according to whether they are more in line with a constructivist, explorative, or instructional approach.

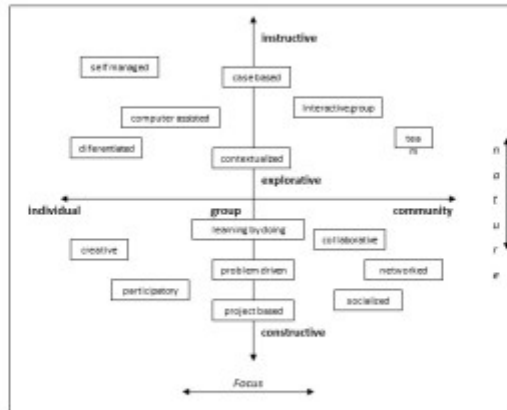


Fig. 4. Horváth's Topography: Approaches to active learning. Source: I. Horváth, M. Wiersma, J. Duhovnik, I. Stroud (2004).

[Video 1](#)

## CHAPTER 3

# Teaching methods

There are a variety of ways of classifying teaching methods according to Neciri (1979) that reflect the form of reasoning (deductive, inductive, and analogical methods) and depend on the activity of the learners (passive methods and active methods) as well as the learner's type of work (individual work, collective work, and mixed work).

Mario de Miguel Díaz (2006) generally structures methodologies according to their organisational modality. The table below shows the classification of methodologies according to the degree of student and teacher participation and highlights in bold the most common methods for each modality.

Table 1. Relationship between modalities and methods according to M. M. Diaz. Source: M. de Miguel Diaz

Organisation modalities	Teaching methods
Theoretical classes	<b>Lectures</b> , case studies, exercise and problem solving.
Seminar-workshops	<b>Case studies</b> , exercise and problem solving, problem-based learning, cooperative learning.
Practical classes	<b>Exercise and problem solving</b> , problem-based learning, case studies.
External classes	Solving exercises and problem, <b>problem-based learning</b> , project-oriented learning.
Tutorials	<b>Learning orientated towards contracts</b> , learning contract
Study and work in groups	<b>Cooperative learning</b> , problem-based learning, case studies.
Independent study and work	Project oriented learning, <b>learning contract</b> , case study, lectures.

[Interaktivní prvek](#)

### 3.1 Description of teaching methods

Below is a description of the seven most common teaching methods for each modality as defined in the table above.

The lecture has been the predominant teaching method in the classroom. It is an expository method which consists of a verbal presentation to students by the teacher. In this method, the role of the teacher as a transmitter of knowledge is of primary importance, and the role of the student as a receiver of knowledge is secondary.

Case studies are based on the presentation and guidance by the teacher of a specific case based on real events and on which small groups of students must understand, interpret, analyse, and resolve the questions raised.

In exercise and problem solving the teacher poses exercises or problems that students solve and interpret through the application of formulas, algorithms, and information transformation procedures.

Problem-based learning is a teaching-learning method in which problems from professional practice or real life are posed as a learning stimulus for students to solve in groups. The teacher poses a problem and the students define what they know and what they need to know to understand and resolve the problem. Problem-based learning shares many of the attributes of cooperative learning with the added feature that the problem is realistic. This approach facilitates a greater understanding and retention of content.

Project-based learning is a 'methodology based on contextualised or real projects that must be solved according to the instructor's indications or guidance'. It is an active learning methodology that is consistent with the assimilation of significant knowledge. An example is the final degree project, which involves carrying out a project that includes the knowledge of various subjects, as an example and synthesis of the training. This is a frequent approach in engineering.

Collaborative or cooperative learning is based on the collaboration of all the participants in the learning process and the responsibility for learning in groups is shared. It is a special type of active learning.

In the learning contract approach, the student must sign a specific and sufficiently detailed commitment to work for a period on given tasks. This learning contract must be ratified by the teacher, who will partially agree with the student the objectives and deadlines, and who will constantly monitor achievement. Students will be informed of any deviations and given clear indications for revising their work.

Table 2. Definitions of the teaching methods. Own elaboration

Teaching methods	Definition
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Lecture	Explanatory method that involves the demonstration and verbal transmission of material and knowledge to the students by the lecturer. The lecturer acts as a conveyor of knowledge, whereas the students adopt a secondary role, acting as the recipients of this knowledge.
Case study	The lecturer presents to students a practical case, based on true facts, and offers guidance. The students, usually working in small groups, assimilate, interpret, analyze and resolve the different issues arising from the case.
Problem solving exercises	Teaching method that involves the lecturer presenting exercises or small problems. The students are expected to interpret and reach a solution by applying formulae, algorithms and information processing techniques.
Problem based learning	Teaching-learning method which draws on authentic problems relating to professional practice as a stimulus for learning. The lecturer poses a problem and the students work in groups to solve it. Students must define both what they already know and what they need to know in order to proceed and solve it. This method facilitates deep understanding and retention of content.
Project based learning	Method where students are engaged in real or simulated projects similar to those conducted by adult professionals. This method gives students the chance to be involved in hands-on, cross-curricular learning experiences, allowing them learning by doing and applying ideas. The lecturer offers guidance throughout the whole project.
Cooperative learning	Cooperative learning is a specific kind of collaborative learning. Students work together in small groups on a structured activity. They are individually accountable for their work and the work of the group as a whole is also assessed. This method is only effective if the following requirements are met: 1) students feel challenged but safe; 2) groups are small enough that everyone can contribute; and 3) tasks to be performed by students are clearly defined.
Learning contract	In the learning contract students sign a firm commitment detailing the duration and number of tasks to be completed. The student pledges to strive to fulfill these objectives, reporting promptly any potential digressions and clearly recording revised work plans. This “contract” is agreed by the lecturer and the student.

[Video 2](#)

## CHAPTER 4

# Virtual mode

The introduction to this paper mentioned how the Covid pandemic has led to the abrupt implementation of virtual teaching. The digitisation of the teaching model in university education was already growing gradually in Europe, but it became mandatory almost instantly.

### DEFINITION

‘We have to recognise that human flourishing is not a mechanical process; it’s an organic process. And you cannot predict the outcome of human development. All you can do, like a farmer, is create the conditions under which they will begin to flourish’. A reflection from the famous educator Ken Robinson.

If we can draw one lesson, among many others, from the experience of lockdown, it is that teaching planning in universities is useful for situations of continuity, but in the face of unthinkable crises, we must put it aside and rely on other factors.

These factors include, and I would highlight as priorities: adaptation to change; educational commitment; flexibility in teaching methods and approaches; and, above all, the integration of human and relational aspects in our teaching. These are sustainable competitive skills to face such difficult and unpredictable life situations – such as those that have affected our students and our own reality as teachers and educational leaders.

It is clear that rethinking education and forms of teaching and learning is a constant need and this crisis has undoubtedly made it urgent and necessary. This has had a positive effect on universities as they are usually highly resistant to change and slow to change practices.

### DEFINITION

Only with the strategic leadership from the top and an important level of commitment from lecturers, supported by sufficient economic resources and guidelines from the political educational establishment, will it be feasible to stabilise a robust and efficient digital strategy that enables changes in the university teaching model to take root.

There are many aspects in the achievement of a remote teaching model or system. One of these aspects is the need to maintain a system of continuous training for teachers that helps them face digital change. It is also necessary to monitor and analyse qualitatively and quantitatively the functioning of virtual campuses (which are the mainstay of online teaching). It is essential to maintain the motivation of our students and foster their relationship with their teacher, class group, school, and university.

Online teaching and tele-teaching can favour many other activities – such as the massive recycling of teaching staff, the executive rethinking of teaching methodologies, and the personalisation of learning at university, as well as encouraging further skills training. These aspects contrast with clearly negative dangers such as a lack of physical interaction, overworking, and the difficulties of evaluation. Despite these elements, the main objective is to maintain the necessary quality standards and a sufficient level of attractiveness.

The hybrid model is gaining ground because face-to-face classes and remote classes can be deployed in parallel.

#### DEFINITION

The hybrid teaching model, also known as blended learning, is a form of teaching that combines face-to-face and distance learning tools and resources – with the aim of improving the student experience and the learning process.

[Interaktivní prvek](#)

## 4.1 Ten guidelines for good online teaching

Let's consider some practical guidelines on how to approach remote teaching at university without 'losing' our students along the way.

1. Check the individual situation of each student.

Check the situation of each student by asking questions in the virtual campus forum or by sending a private email. This option enables us to receive more honest and more personalised answers and check which students can follow the classes.

2. Clarify how the subject will be assessed in great detail and as soon as possible.

It is important to monitor all the tasks for all the subjects. We must know how to time and pace the effort we ask of our students. Therefore, we must clarify and inform all the students about how the subject will be evaluated.

3. Be specific about the definition of tasks and in the computation of the associated workload.

It is necessary to be specific and clear on how and when. Determine which ICT tools students will need, check what they know, and clarify how we will use them. Clarify the class timetable and when videos, audios, and documents will be uploaded. Tell them when homework will be required and how it must be submitted. Remember to tell them when is the best time for them to ask any questions. Also remember the ECTS concept – and measure the amount of work we can demand so that everything is transparent. This will require a lot of communication and in considerable detail.

### DEFINITION

The ECTS (European Credit Transfer and Accumulation System) measures the student workload or hours of study. It measures the work that students must complete to acquire the knowledge, skills, and abilities necessary to pass the study plan. This estimate includes personal study time, tutorials, internships, projects, etc.

4. Regularly ask students for feedback

One of the most necessary tasks when teaching online is to obtain continuous feedback on student progress. Ask for feedback from students every week, such as the submission of an assignment or participation in consultations. The homework could be a summary of an uploaded theory, or an answer to a question from the syllabus, the completion of a self-assessment questionnaire, or a recording explaining a topic.

5. Respond quickly to tasks completed

Weekly assignments or submissions need to be assessed and responded to quickly (no more than 24-48 hours). Students need to know that they are being monitored. The extrinsic motivation of attending class in person must be replaced by a new form of constant commitment over time. It is also essential that the solution guidelines are communicated after an assignment has been handed in. Offering the corrected

answers to each assignment is essential. We must go beyond just giving a grade.

6. Include the concept of self-assessment in the evaluation formula.

Do not be afraid to ask students to make their own assessment so that they learn to assess themselves. It is good practice in the learning process for learners to assess themselves. Try to include methods for measuring engagement in their own assessments.

7. Encourage active participation in remote sessions as much as possible.

When teaching online, the class can be attended synchronously or asynchronously. If it is synchronous, ask them to use the chat and ask questions. You can even require everyone to ask at least one question. Or ask them questions – depending on the number of students per session. This approach generates attention and therefore motivation. If it is asynchronous, consider generating multiple-choice questions at the end of each topic that must be answered before moving on to the next topic.

8. Do not be afraid to innovate

I also highly recommend using that phrase from May '68: 'Power to the Imagination'. Be creative, open a Twitter account for them to post ideas, answers, or contributions. Make a blog and have them record themselves on Instagram showing a model or an item that they have designed. Prepare a Kahoot, and so on. There are so many ideas to try as well as the more traditional ones such as reading a book or an article. Let there be some play and gaming. Rethink how to interact with students in less conventional ways.

9. Online teaching does not exclude encouraging teamwork

Ask students to connect and interact with each other. The idea of generating group work, study groups, team projects, and collaborative work motivates students and creates strong bonds.

10. Maintaining motivation

An important aspect of student motivation is the contact and bonding with classmates. Therefore, we should not neglect this interaction just because teaching is online. It is essential to generate a motivational feeling of belonging so that they bond with the university.

Table 3. Recommendations for good online teaching. Own elaboration

Ten recommendations for online teaching
Check the situation of each student
Clarify in great detail, and as soon as possible, how the subject will be evaluated
Be specific in defining assignments and calculating the associated workload
Regularly ask for feedback from students
Give quick feedback on assignments
Integrate the concept of self-assessment into the evaluation formula
Encourage active participation in remote sessions as much as possible
Do not be afraid to innovate

Encourage teamwork

Maintain motivation

[Video 3](#)

## CHAPTER 5

# Test