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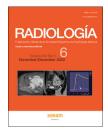
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SERIE: THE CHALLENGES IN UNDERGRADUATE RADIOLOGY EDUCATION

Teaching methodologies in the undergraduate teaching of radiology

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Abstract   After introducing what is understood by teaching innovation and its requirements, various methodologies that can be applied in university and radiological teaching are presented, such as: the flipped classroom focuses on the student's previous study and the teacher's subsequent contribution to resolve doubts or highlight important aspects. Team learning or cooperative teaching allows learning among the students themselves. Problem-based or case-based learning encourages students, in teams or individually, to carry out structured learning based on learning objectives. Teaching based on games or simulation can facilitate knowledge acquisition playfully and practically. Personalized tutoring allows the transmission of knowledge in an individualized way. Various evaluation modalities that can be used for training purposes are also shown.

Metodologías docentes en la enseñanza de la radiología pregrado

Resumen   Tras una introducción de lo que se entiende por innovación docente y sus requisitos, se presentan diversas metodologías que pueden ser aplicadas en la docencia universitaria, y por tanto de la radiología, como: La clase inversa, que se centra en el estudio previo del alumno y el posterior aporte del profesor en la resolución de dudas o realce de aspectos importantes. El aprendizaje basado en equipos o la docencia cooperativa permiten el aprendizaje entre los propios alumnos. El aprendizaje basado en problemas o en casos favorece que los alumnos, en equipo o de forma individualizada, realicen un aprendizaje estructurado en base a objetivos docentes. La enseñanza basada en juegos o en simulación puede facilitar la adquisición de conocimientos de forma lúdica y práctica. La tutorización personalizada permite la transmisión de conocimientos de forma individualizada. También se muestran diversas modalidades de evaluación que pueden ser empleadas con fines formativos.

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Introduction

The implementation of teaching innovations is a process that requires planning, rigour in its application and subsequent evaluation of the results, in order to demonstrate the validity of the innovation. Throughout history, changes have been introduced in the way teaching has been delivered, generally applied according to the circumstances of the moment. Teaching based on reflection and the example of the Greek classics or teaching by means of lectures in the Middle Ages has been and still is used today. However, society has changed considerably and the media available today means that the student is no longer so much concerned with what the teacher is passing on, but turns to other sources of information that are more attractive to him or her or better suited to his or her way of learning.

In this context, different teaching methodologies have emerged that have adapted the useful principles of classical methods to the current reality and current needs, where skills learning is a priority; where teachers must find among the tools at their disposal, those that help them to improve the transmission of knowledge; while the student must accept that this is the time for responsibility and personal autonomy in order to grow. Students must not only know, but also show how to do and even how to be.[1–3]

The aim of this article is to review and provide information on the different methods that have been developed in recent decades in the field of teaching in general and that are being applied in university education and, therefore, in the teaching of radiology.

Innovation and new teaching methodologies

Innovation is a process that seeks to improve the quality of teaching. It involves being clear about the objectives to be pursued, the method to be used and evaluating the effectiveness of the changes. Increasingly, the various teaching techniques focus on learner development and active learning, self-learning and collaborative and cooperative work. ''One should not aim to revolutionise teaching: it is preferable to create quality content little by little rather than a lot of poorly thought out and poorly put together resources''.[1]

The new teaching methodologies are characterised by a number of features that define teaching in terms of transformative learning.[2] These features are:

Competence training
Competence is defined as the set of knowledge, skills and attitudes that students must develop and attain throughout their academic education. This requires knowledge to be generated and passed on. Learners need to have internalised the basic knowledge, and it is not useful just to learn how to look it up. They need to acquire specific skills or abilities that they can apply in their future careers, and also to develop attitudes that will allow them to develop personally, generating a spirit of growth.

Training in true critical thinking
Teaching the learner what is important in any problem or process, to weigh up different points of view, to know how to ask key questions, what purpose is being pursued, to consider the possible implications and their consequences.

In this area, teaching should focus on providing the material and posing thought-provoking questions, allowing time for reflection and facilitating comparison with others. Teaching dialogue, argumentation and creativity.

Promoting learner autonomy
Autonomous learning is a process that allows students to be the protagonist of their own development, being able to reflect on their own learning process and to make personal decisions in line with this reflection, as well as integrating their own education and training, that received from the teacher and that from their peers, into the learning process.

The task of the teacher is to guide this learning to gain autonomy so that students set realistic goals for themselves, encouraging self-evaluation, reflection and critical thinking, as well as tolerance of frustration.

Building a sense of service
Generating in students the responsibility of service to others, with generosity, which leads them to confront the problems that arise in society and to try to find the best solution. Research and teaching should be reflected in others. Transmitting ethical values and generating human relations.

Training in integrated and integrative knowledge
The compartmentalisation of knowledge has led to specialisation, but it must promote spaces for reconciliation and dialogue between subjects. It requires integrating knowledge, teachers and teaching methods.

Teaching methods or techniques

Flipped classroom

Flipped learning is a pedagogical model that has proven its effectiveness through different means.[4–6] It consists of providing the student with the study or learning material, so that he/she can work on it independently, before attending a face-to-face session with the teacher. This is mainly used to facilitate and enhance other processes of knowledge acquisition and practice in the classroom, such as resolving queries, highlighting important aspects, clarifying difficult concepts or raising issues of interest related to what has been learned. In so doing, at the end of the class, the student has developed thinking skills beyond remembering or learning, favouring more meaningful learning.

This methodology is based on four pillars: flexibility of the learning environment, a culture of learning, pre-determined content and the changing of the teacher's role.[1]

Teachers no longer only pass on knowledge, but must be multidisciplinary and a facilitator. They create the content, guide the learning process and provide continuous feedback to the learners. This allows the teacher to focus on clarifying complex problems in a more personalised and learning-friendly way.

The materials can be self-produced texts, selected articles, book chapters, videos, case studies or case studies with commentary, etc. This material, which the learner receives in advance to work with, should be sufficient for the acqui-

sition of the fundamental knowledge and enable learning, but not so excessive that it requires too much time to work through and understand. Content will be assimilated partly through their personal activity of study, research and discovery.

The face-to-face session can be structured in different ways, but it is recommended to evaluate what has been learned by means of surveys or tests, before or at the beginning of the class. This allows the teacher to find out whether students have internalised the knowledge and to identify the points of greatest difficulty.[4,7] Based on the results, the class can focus on resolving queries or concisely presenting the relevant aspects. The main part of the face-to-face class is used to practically apply previously acquired knowledge by posing and resolving problems

Results in published studies show that this methodology has advantages over the traditional classroom, improving assessment results and student satisfaction.[4–9]

In summary, the learner studies the recommended material before the class, a short evaluation is carried out that is used to detect any deficiencies, and the face-to-face session is used to resolve queries, emphasise the important aspects and put the acquired knowledge into practice.

Team-based and cooperative learning

Team-based learning (TBL) is a methodology based on flipped learning that favours active and effective learning and teamwork,[10] which can be applied to large groups of learners.

Students acquire knowledge individually by reviewing the materials prepared by the teacher before the class. The class is then divided into groups of five to seven students. The groups should ideally be heterogeneous in terms of the ability of the students, and should be maintained throughout the course in order to foster cohesion.[11]

Once distributed, an *individual test* is given to check the level of preparation. This test is administered at the beginning of the class to motivate students to arrive with the material prepared. The students then repeat the same *test in teams*, generating a discussion within the groups that favours learning through contributions by each individual member. To be sure that students have acquired the knowledge, the teacher offers a short discussion or *mini-lecture* to clarify key concepts or those that remain problematic for the students.

After this first part, the knowledge gained is applied practically, *solving significant problems* pertaining to the subject studied.

Teams of students jointly discuss and find solutions to significant subject-related problems, applying what they know. This dynamic allows them to broaden their knowledge, make judgements and decisions that are presented to the class as a whole. This can be followed by a discussion, where students receive specific and timely feedback on the quality of their thinking and the process of arriving at their decision.[11]

The design of the problem or case is key to ensuring the learning outcomes of the teaching activity. The problem designed must comply with the 4S framework:[10]

- *Significant problem:* significant or relevant problem pertaining to the subject.
- *Same problem:* same problem for all teams.
- *Specific choice:* must have a specific and clear answer.
- *Simultaneous report:* must be answered by all teams at the same time.

This framework requires an average time of two to three hours and is ideal for integration sessions with other subjects. In our experience, we have applied it in the subject of anatomy, combining physics, radiology and classical anatomy problems.

A variant of this methodology is what Robert Slavin[10] defines as *cooperative learning*, a process in which students work together in groups to master material initially presented by the instructor, such as a clinical-radiological case. For this methodology to be useful, teamwork must be encouraged as much as possible, promoting interaction between students so that they learn the content and didactically encouraging or promoting the need for them to work together.

The teacher must foster conditions conducive to effective cooperative action. For true cooperative learning to take place, five basic elements must be taken into account:[12]

- *Positive interdependence.* Students need to feel that they are linked to others in the group in such a way that their own success is conditional on the success of others.
- *Interaction.* Students should be able to stimulate each other's efforts and personally promote each other's learning.
- *Personal responsibility.* Each student must be responsible for his or her part of the teamwork. The teacher should evaluate individual efforts, provide feedback to groups and individuals, and ensure that everyone is accountable for the final outcome.
- *Social and small group skills.* Students have to learn both academic subjects and the skills needed to function as part of a team. The more these skills and knowledge are developed, the better the outcome of the activity will be.
- *Evaluation of the group process.* In addition to assessing the work done by each individual student, the teacher must assess the teamwork of the students so that the group is committed to working cooperatively.

The teacher should[10]:

- Plan conceptual and attitudinal objectives; create groups and distribute students accordingly; determine working time; generate and provide learning materials; and assign roles to group members.
- Explain to students the methodology and what they will be doing during the lesson.
- Coordinate the lesson, supervise learning groups and intervene and assist, where necessary, to improve task execution and teamwork.
- Organise post-lesson activities, promote reflection within the group on how the group functioned and evaluate how the groups functioned during each session.

Evaluating this methodology requires extensive experience in handling groups and being attentive to the development of group work, based on criteria that are as objective as possible.[13]

In short, it is about peer learning or teaching each other by working together to improve each other. Groups may have uncooperative elements, but these are aspects that then also occur in daily practice and students must learn to manage them. It requires the teacher's expertise to maintain the group dynamic and identify problems.

Case-based teaching

The case method is a methodology that involves presenting the definition and description of a case, an incident or a real-life event.[1] Studies, articles or texts can be added to complement the reading and subsequent research, but the defining feature of this method is that the case being worked on is something that has occurred in real life.

Case studies are interesting when you want to bring an element of reality into the classroom, when the area of study is complex or when you want to work on skills such as analysis, understanding, discussion and group work or the search for possible solutions to a problem. In radiology, it is a widely known and applied methodology that encourages active learning in the student, because it starts from the specific and then moves on to the general.[14] Cases can be used to generate discussion, deciding on concrete solutions or simply without arriving at a single solution. The role of the teacher in a case study is to lead the discussion and promote sharing in relation to previously set learning objectives.

Working with actual cases is very dynamic and engaging, both for the teacher and the students. A clinical case and its basic information can be used as a starting point to work on issues such as the indication of complementary tests. The corresponding images can then be shown, followed by a discussion of the technical quality, anatomical aspects, signs of pathology, their relationship to symptoms, differential diagnosis, further recommendations or treatment. Sharing or discussing with peers is an important part of the learning process for students. This allows the teacher to better understand how they process the content, the type of thinking and relationships that are established. It also allows for the identification of possible gaps or difficulties in the students' understanding.[14]

In short, this is a common and well-known practice that should be developed more widely, usually in small groups.

Problem-based learning

This is a methodology that promotes self-learning and reflection by the student by employing reasoning strategies to combine and summarise the information provided by the problem or situation into one or more explanatory hypotheses. In so doing, it enables students to identify learning needs and, based on what they have learned, to identify principles that can be applied to other situations/problems.[15] It can be applied to small groups of students.

One of the most commonly-used frameworks in *problem-based learning (PBL)* is described below, done over two sessions.

First session:

Step 1. Presentation of the problem to the group, usually in writing.

Step 2. Inductive work with instructions to discuss the problem and identify learning objectives of interest to the group.

Step 3. Selection of study topics and in-depth study (learning objectives).

Individual work by the student, which explores in depth the agreed learning objectives in relation to the problem posed. This can take place over a period of one or several days.

Second session:

Step 1. Learners present their topics and discuss within the group what they have learned, identifying areas of doubt related to the learning objectives and relevant to the problem.

Step 2. Teacher clarifications and discussion, solving the initial clinical case.

Teaching based on PBL in undergraduate medical education, and therefore also in radiology, is being developed in some universities.[10,11] Several articles have analysed the effectiveness of PBL in radiology teaching, which allows integration with pathology and anatomy and helps the student to understand the importance of radiology in medical practice.[16,17] PBL appears to be more effective in radiology education than the traditional teaching method, with positive effects on students' interest in learning, team spirit and oral expression.[18,19]

In short, it is a proven and well-structured methodology to be implemented in separate sessions with small groups.

Online teaching

The COVID-19 pandemic forced the development of online training using the tools available at the time, converting primarily face-to-face education into completely virtual learning. Most opted to convert traditional classes into videoconferences. However, online teaching tools are highly diverse and provide new environments that are more flexible and adaptable than traditional learning methods, enriching the content.[20]

Online training tools[21]:

- Virtual lectures (videoconferences, audio presentations).
- Interactive case reading – radiological case files – cases of the day.
- E-learning courses and tutorials.
- E-mail, forums, chats, videoconferences, telemeetings, etc.
- Atlases, image collections, radiological case files.
- Image search engines.
- Websites of radiological journals. Article and journal search engines.

Virtual learning environments, also called learning management systems and virtual classrooms, are educational platforms that allow different educational materials (includ-

ing videoconferences, tutorials, study material, links to external resources, quizzes, practical tasks, etc.) to be implemented and organised and learning to be assessed, while facilitating communication between teachers and students through discussion groups and collaboration.[20]

As a whole, they are considered complementary to the other methodologies, but complete courses on specific subjects can be configured, exploiting the use of these technologies to ensure that students acquire the necessary skills. The study by Viteri Jusué et al.[21] demonstrates the effectiveness of this type of specific course in improving radiology learning.

Teaching simulations

Simulations are teaching initiatives that allow students to experience their future professional activity. The student applies their knowledge learned and puts skills into practice, not just purely theoretical knowledge. Simulation promotes the use of critical and evaluative thinking. Simulations are formulated as problems that prompt students to come up with proposed solutions. Simulation stimulates learning because students experiment with different concepts. Both their emotional involvement and their memory retention capacity are higher.[1]

There are different types of simulation, some of which are more suited to particular subjects of study than others. Most simulations involve elements of theatre, games, competition or metaphor, and even actors, which are very commonly-used in medical and nursing subjects.[22] Manikins are now available in medical faculties that facilitate learning and manipulation even with ultrasound simulators.

Where infrastructure such as simulation classrooms are available, complex medical scenarios can be recreated to put the student's knowledge and their practical and attitudinal skills into practice, involving different specialties.[22] Radiographic and ultrasound equipment can be made available to recreate the scenario and force participants to practice and solve diagnostic imaging problems.

Learning for an OSCE (objective structured clinical examination) can be considered to fall within this methodology and can be used for both summative and formative assessment.

Gamification or game-based learning

Gamification is a learning methodology that brings the mechanics of games into the classroom environment in order to facilitate learning for students. It is essential to be clear about the learning objectives of the game: think about objectives that are aligned with the subject and that help the learner. To avoid the common misconception that games are superfluous entertainment, it is important to communicate clearly to learners the objectives pursued and to promote more active participation, which increases motivation and stimulates learners' social connections.[1]

The gamification techniques used in the classroom should follow a development process that Marne et al. define in six facets:[23]

Pedagogical objectives: define the scope and represent it through models indicating the domain of knowledge. The modelling should be constructed together with the pedagogical experts as they are the ones who provide the context.

Domain simulation: the game should have clearly established rules and parameters.

Interactions with the simulation: the mode of interaction is important because it leads the student to learning.

Problems and progression: the methodological route that places the series of learning challenges in the order required to achieve the objective. Feedback concerning the progress made by the player should also be specified.

Decorum: the multimedia elements used to attract the player's attention.

Conditions of use: specify by whom, when, where and how the game will be used.

The context in which the game serves its purpose and the rules of that context should be specified. A game can be virtual or asynchronous, played as a group or individually, to name but a few variations, but always with a learning objective.[24]

Gaming has proven to be effective in the training of healthcare professionals and has an important role in undergraduate and postgraduate training in diagnostic radiology. These activities can be carried out either in real environments or in classrooms or meeting rooms, but there are also interesting online modalities that favour remote access and user management.[24]

Various experiences have been published, such as Escape rooms, team or individual competitions, both face-to-face and online using applications such as *Kahoot* or in virtual environments.[25]

Personalised tutoring

Personalised counselling programmes for the development of professional and personal skills is a methodology that allows for personalised educational development, providing, in addition to theoretical and practical knowledge, the acquisition of attitudes.[1] Personalised teaching of one or more learners involves the direct transmission of knowledge, attitudes and values, usually in a practical environment.

In this methodology, the relationship between teacher and student is very close, with the teacher being the role model, the guide in the transmission of knowledge and the stimulus for learning. In radiology, the student comes not only to listen to information, but also to learn why a study is performed, how it should be read, what the implications of the results are and what the radiologist's job is in the whole process.

This methodology is usually accompanied by formative assessment, with mini-CEX (Mini Clinical Evaluation Exercise)[26] tests where the student demonstrates their skills with real cases and applies what they have learned, by implementing structured rubrics appropriate to the practice. This is followed by the tutor's recommendations and the student's own reflection on the effort they have made and the achievement of the objectives, accompanied by recommendations or suggestions and complementary materials for their achievement.[1]

In short, it is the individual learning that takes place in clinical practice and requires some structure to achieve the

Table 1 Summary of teaching methodologies.

Method	Characteristics	Requirements
Flipped classroom	Large groups Personalised to the learner	Student engagement and teacher flexibility
Team-based learning	Large groups Structured approach	Learner engagement and knowledge of group dynamics
Cooperative learning	Small groups Peer-to-peer learning, teacher-led	Learner engagement and knowledge of group dynamics
Case-based learning	Small groups Dynamic and reality-based	Knowledge of the dynamics of learning in groups and leading them
Problem-based learning	Small groups Very structured Promotes reflection and student work	Divided into several small group sessions
Online teaching	Highly diverse material	Preparation of teaching materials and assessment of student work
	Unstructured student work, depending on their availability	Establishing a relationship with the distance learner
Teaching simulation	Dynamic and based on real cases	Specific infrastructure and adequate preparation is needed
Game-based learning	Fun and appealing	Requires clear rules and infrastructure
Personalised tutoring	Direct and experiential learning based on reality	Large and committed teaching staff
Formative assessment	Knowing what you know and what you do not know	Feedback work
	Recommendations for improvement	Preparation of multiple assessments

required skills, requiring the involvement of the coordinator to teach and assess them appropriately.

Assessment

All the methodologies described, with their well-defined pedagogical structure and varying effectiveness, must be aligned with coherent evaluation. It is nonsensical to change the teaching methodology, trying to get students to achieve skills and deeper learning, if we do not adapt the assessment systems. As such, the pedagogical effort of teachers must also be oriented towards the design of assessment systems that make students demonstrate that they have met the learning objectives of the different methodologies. The multiple-choice test, which is widely used to assess the knowledge of medical students, can determine the degree of knowledge acquired at a particular point in time. It is important that questions are asked correctly, avoiding negative statements, confusing or inconsistent distractors. In addition, it is always advisable to carry out a subsequent evaluation of each question to determine its validity, degree of difficulty and discrimination.[27] However, this type of exam should be accompanied by other assessment methodologies: short application questions, clinical case resolution, self-reflections, mini-CEX, OSCE, etc., in order to obtain a more objective and appropriate view of the student's real learning and to assess not only knowledge but also skills and attitudes.[28]

A specific way of applying assessment is the so-called *formative assessment*. This is a teaching element that promotes personalised education, as it identifies learning difficulties in the student during the learning process, which can be corrected. New technologies make it easier to evaluate learning development as often as is required.[29] This feedback allows students to ''identify what is important to learn, what they have learned well and what they need to spend more time on''.[30]

There are four characteristics of this methodology: the specific organisation of the course, motivation, student participation and constant feedback.[31]

This methodology is complementary to any of the other teaching techniques that may be used. It requires the creation of a large bank of questions, allowing randomised use, classified by topic and designed to determine learning progress and the acquisition of skills.

Although it requires intense dedication on the part of the teacher to develop quizzes, apply them, evaluate responses and propose improvements in learning, it is currently one of the most widely-used forms of learning in Spanish specialty training (Médico Interno Residente, MIR) programmes, together with simulations. From these, the learner deduces his or her level in relation to the environment or the teacher's requirements, considers areas for improvement and establishes needs.

Even in face-to-face classes, it is advisable to start with a short questionnaire that can nowadays be administered with immediate-response applications through electronic devices (mobile phones, tablets or computers), which allows students to review their knowledge of topics already taught or to determine what they know about the topic to be taught. It is a useful tool to identify the student's starting point and to get the learner used to the type of questions that will be posed in the final or summative assessment.

A summary table of the methodologies is included (Table 1).

Conclusion — final reflection

The application of new teaching methodologies seems necessary in a changing teaching environment that requires continuous improvement of student-centred teaching.

All the methodologies discussed above seek to encourage self-learning and reflection by the learner, accompanied by a change in the role of the teacher. However, they must be applied with a clear understanding of the objectives, selecting and using the most appropriate tools and objectively evaluating the results, remembering that, ultimately, what makes the system work is not the structure or the technology, but the passion of the teacher, the commitment of the learner and the personal relationship between them.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Authorship

J.D. Aquerreta Beola: Drafting of the manuscript.

L. Arbea Moreno: Revision, correction and important contributions.

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