Modern technologies and distance learning in Science didactics

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ABSTRACT. Both distance learning teaching and traditional teaching present positive and negative characteristics. If on one side the former lack of continuous contact with learners, some author recently pointed out how classic educational scheme begins to show its limits, suggesting lecturers to explore alternatives. Some are quite sophisticated in using course websites, blogs, and other means to get in touch. The availability of online video and increasing student access to technology has paved the way for "flipped classroom" models. In such a model, traditional teaching methods are inverted and instruction and lessons are delivered online outside of class moving homework into the classroom. Flipped classroom is a form of blended learning in which students learn content online, usually at home, and homework is done in class with teachers and students discussing. Many instructors have pointed out as well the benefits of teaching by questioning over the more traditional approach of teaching by telling, a model called "peer instruction" and essentially based on an interactive learning principle, developed by Harvard Professor Eric Mazur in the early 1990s and used in the beginning to improve learning in introductory undergraduate Physics classes at Harvard University. Peer instruction is a student-centered approach that involves flipping the traditional classroom by moving information transfer out and moving information assimilation and application into the classroom. Active learners are requested not just to take note of new information, but to apply it, involving students and preparing to learn outside of class by doing pre-class readings and answering questions about those readings. In the present article, such modern teaching methods and their possible application to distance learning scientific courses will be discussed, emphasizing how the interplay between the two could allow distance learning teaching to close the gap with respect to traditional didactics, as well as possibly permitting to surpass its limits.

KEYWORDS: *Flipped Classroom, Interactive Learning, Peer Instruction, Science didactics*

Introduction

Recent years have seen the creation not just of techniques and teaching models based on the use of new information technologies, but also the birth of new traditional teaching methods trying to overcome the limitations of conventional teaching.
In fact, from one side the development of computer technology in recent decades has provided communication tools with a level of sophistication so high to make possible and comfortable to enjoy any kind of contents, including those normally present in university lectures. On the other hand, in the last years we assisted to a large increase of universities and professional courses completely delivered online thanks to modern technologies, as more and more faculties find that the traditional lecture no longer suits them and they are watching with interest to the emerging of new teaching methods, most of which make use of alternative ways to connect with students.
While distance learning and new technologies based courses have also its limits, even though of a different nature compared to the traditional teaching, the current tendency sees the use of modern technology as a point of strength in every field of teaching. Even if distance learning courses lack of continuous contact with learners, on the other side some author recently pointed out how classic educational scheme presents also many limits as they do not always fit the needs of all disciplines and all fields of application (Mazur, 1997).
These considerations suggest that it might be time to explore alternatives in order to try to formulate a didactic method that does not overlook the classic standard, but that at the same time shows a higher level of dynamism and versatility.
The main topic of the present article concerns with a possible implementation of modern teaching methods in e-learning courses, with a particular reference to scientific disciplines and for some specific examples to the teaching of Physics.
Firstly, what limitations emerge when traditional teaching is considered will be explored. Then the basics aspects of two modern teaching methods will be discussed and a methodology to evaluate the effectiveness of students' preparation, which implies somehow also a measure of the teaching/learning quality, will be illustrated.
Eventually, all this ingredients will be put together, showing how they can be applied to e-learning and used to deliver online courses of better quality.

Limitations of traditional teaching

One of the main problem of traditionally taught courses concerns with the way in which lectures are given. The classic educational scheme, in which a teacher stands in front of an audience lecturing, could have the serious disadvantage of inducing passivity in bystanders.
Usually only a small percentage of class actively follows the discussion and asks questions and becomes difficult to hold students attention for long periods: students in a lecture class can sometime give the impression of lethargy.
As a consequence, no adequate opportunity is given to students to critically think through the arguments being developed.
Another problem with conventional teaching lies in the presentation of the material. Frequently, it relies on textbooks and lectures adds little new information than the one present in lecture notes,

giving students little incentive to attend class. That the traditional presentation is nearly always delivered as a monologue in front of a passive audience compounds the problem. Only exceptional lecturers are capable of holding students' attention for an entire lecture period, anyway it is even more difficult to provide adequate opportunity for students to critically think through the arguments being developed.

When moving to Science lectures, such problems can become even more critical because of the special attention that these disciplines require to be comfortably enjoyed. As a consequence of the normal structure of scientific courses, lectures induce students' belief that the most important step is solving problems.

Consequently, lectures simply reinforce students' feelings that the most important step in mastering the material is solving problems. The result is a rapidly escalating loop in which the students request more and more example problems so they can learn better how to solve them, which in turn further reinforces their feeling that the key to success is problem-solving.

Such behavior becomes even more evident when Physics introductory courses are considered. For most students, the ultimate value of an introductory physics course lies not in learning, for example, laws of mechanics, but in acquiring the skills a physicist uses in working with such laws. Important skills, transferable to other areas, include simplification, idealization, approximation, pictorial, graphical, and mathematical representations of phenomena and, more generally, mathematical and conceptual modeling. Anyway the idea that physics is made up only by equations and mathematics is such an established fact among students that many of them will refuse to think if they can find an equation to memorize as an alternative.

All this critical aspects are further emphasized if we consider that the way physics is taught in the today is not much different from the way it was taught 100 years ago, to a much smaller and more specialized audience.

What is needed then is a way to focus attention on the underlying concepts without sacrificing the students' ability of solving problems. The method should be adaptable to the use of modern technologies so to deliver courses on-line, allowing if possible also a more personalized students' assistance.

A discussion centered didactics: peer instruction

Since many years, the physics community has been engaged in trying to find the best way to teach introductory physics to undergraduates students belonging to those courses of study in which physics, and in general science subjects, are not the main topic, but rather a complement.

Building on research in cognitive science, physics educators have created new approaches, new demonstrations, interactive and innovative software, and some new content to make the teaching of physics more effective and the study of physics more attractive to a wider group of undergraduate students.

Physics teacher are now trying to disseminate some of these new undergraduate approaches. Implementation however could be challenging as faculty often encounter institutional constraints that limit the degree to which they can apply these new ideas to standard courses.

As already pointed out, students usually develop the feeling that the best way to study scientific subjects consists in concentrating entirely in learning problem-solving strategies and they don't linger enough on trying to understand the underlying conceptual aspects. Such situation is further aggravated by the fact that students usually come to study scientific disciplines with "misconceptions" about the basic ideas.

Indeed, students enter their first physics course possessing strong beliefs and intuitions about common physical phenomena, but these notions are derived from personal experience and influence students' interpretations of material presented in the introductory course. Halloun and Hestenes show that instruction does little to change these "common sense" beliefs (Halloun, Hestenes, 1985a; 1985b; 1987; Hestenes, 1987).

For example, after a couple of months of physics lessons, all students can memorize Newton's third law and most of them can apply it in numerical problems. A little probing however quickly shows that many students don't reach a real understanding of the law. Halloun and Hestenes provide many examples in which students are asked to compare the forces exerted by different objects on one another. When asked, for instance, to compare the forces in a collision between a heavy truck and a light car, many students firmly believe the heavy truck exerts a larger force.

There are many other examples of conceptual problems students find difficult to handle, like a simple application of the physical quantity "work," defined like $L=F \cdot s$ where F is the vector force and s the vector representing body's displacement. Let's for instance imagine a body of given mass M moving by a known distance s on a horizontally level surface while subjected to gravitational force. In this case a proper understanding of the definition of the physical quantity work, allows one to argue that such a quantity is zero for the situation considered, without the need of performing any calculation, as the scalar product between F and s include a cosine which is zero when the two vectors are perpendicular. Also it is possible to conclude intuitively that the gravitational force isn't responsible for the displacement, being perpendicular to the displacement s. Still many students, when asked such question, complain that they can't reply as numerical parameter about M and s are not given. Anyway, even with such misunderstanding on the basic subjects, students were able to successfully solve numerical problems of any kind.

These simple examples expose a number of difficulties in Science education. First, it is possible for students to do well on conventional problems by memorizing algorithms without understanding the underlying physics. Second, as a result of this, it is possible for a teacher, even an experienced one, to be completely misled into thinking that students have been taught effectively. Students are subject to the same misconception: they believe they have mastered the material and then are severely frustrated when they discover that their plug-and-chug recipe doesn't work in a different problem. Such situation is very well described by the following citation: "The danger with lucid lectures – of which we have so many on this campus, with so many brilliant people – is that they create the illusion of teaching for teachers, and the illusion of learning for learners" (Eric Mazur, professor of Physics at Harvard University).

In the early 1990s, in order to remedy the high incidence of conceptual errors similar to the ones described, Harvard Prof. Eric Mazur developed the Peer Instruction teaching method (Mazur, 1997). Its basic aims consist in teaching the conceptual bases in introductory Physics focusing students' attention on underlying concepts and promoting understanding instead of memorization of concepts and equations.

A Peer Instruction taught lesson exploit student interaction during lectures giving them time to discuss about the conceptual aspects of the argument being developed. Such an approach leads to a general better student's performance for it results in a stimulus for students to think, not just to concentrate on the solving of exercises.

Eric Mazur's Peer Instruction shows teachers how to challenge students to think about the physics instead of juggling equations. Peer instruction as a learning system involves students preparing to learn outside of class by doing pre-class readings and answering questions about those readings using another method, called Just in Time Teaching. Then, in class the instructor engages students by posing prepared conceptual questions or "Concept Tests" that are based on student difficulties.

Instead of presenting the level of detail covered in the textbook, lectures consist of a number of short presentations on key points, followed by "Concept Test," i.e. short conceptual questions on the subject being discussed. Each Concept Test has the following general format: it focuses on a single concept, is not solvable by relying on equations and has adequate multiple-choice answers.

In a typical Peer Instruction lesson, students are first given time to formulate answers and then asked to discuss their answers with each other. This process allows students to think through the arguments and clarifies any misunderstanding for each student has to discuss with his neighbor about the problem considered and explain its own understanding of it. By doing so, any student has the possibility to deepen and test his or her understanding of any concept presented.

The questioning procedure outlined by Eric Mazur, which represents also the basic structure of a Peer Instruction lesson, is as follows.

1. Instructor open the lesson giving a brief lesson on just one key topic, then poses question on such a topic the class
2. Students reflect on the question and commit to an individual answer
3. Instructor reviews student responses and students discuss their thinking and answers with their peers
4. Students then commit again to an individual answer on the same problem
5. The instructor again reviews responses and decides whether more explanation is needed before moving on to the next concept

The procedure is sketched in Figure 1, from which is clearly evident the cycle structure of a Peer Instruction driven lesson. Every student deals with the same "Concept Test" two times, before and after discussion with his or her neighbors. During the discussion all students' misconceptions clarify up in a much deeper way than the one obtainable with a classical lecture.

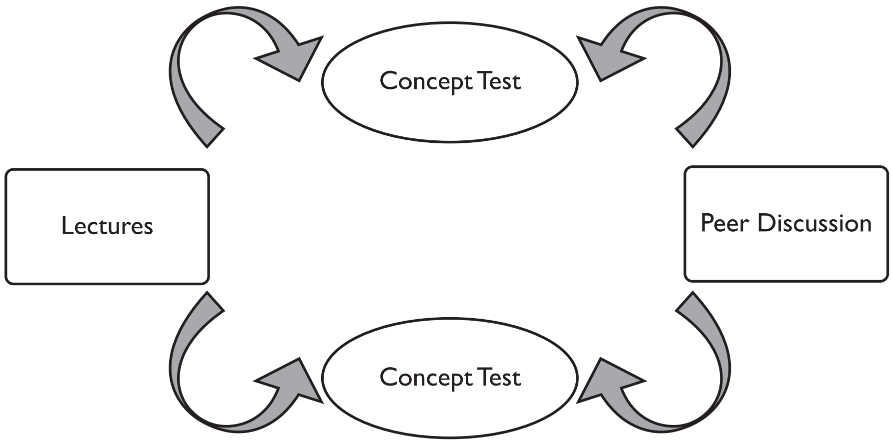

Figure 1. Peer Instruction schematic. After a brief lesson, students are asked to reply to some specific "Concept Test" first alone and then after discussion with neighbors

These tests don't replace classical problems, but supports them to provide a better understanding of the phenomena. In order to not make problem-solving skills suffer, traditional exercises can be either included in lectures or left to homework assignments.
Nowadays, Peer instruction is used in various disciplines and institutions around the globe and research demonstrates the effectiveness of peer instruction over more traditional teaching methods, such as pure lecture. Peer instruction is now used in a range of institutional types around the globe and in many other disciplines, including Philosophy, Psychology, Geology, Biology, Math, Computer Science and Engineering.

Moving to e-learning

Peer Instruction overcomes many of the limitations of traditional teaching, but in its classical application does not envisage the use of distance learning technologies. A very interesting question is therefore whether such innovative and very teaching model can be implemented also to distance learning courses.
Anyway application to distance learning courses is not straightforward and when moving to e-learning three fundamental aspects have to be faced, such as on-line implementation, the possibility of enabling group students' discussions and the possibility of giving personalized assistance, which implies the deployment of an assessment method of students' progress.
The on-line applicability is guaranteed when considering the so-called "Flipped Classroom" model (Abeysekera, Phillip, 2014). Flipped Classroom is a teaching methodology and a type of blended learning (Friesen, 2012) that delivers lesson content outside of the classroom and moves activities into the classroom. Students can then watch lectures at home at their own pace and communicate with teachers online. As a consequence, educational technology and activity learning are two key components of the Flipped Classroom model.
In contrast to the traditional teacher-centered model of classroom learning, the Flipped Classroom moves instruction to a learner-centered model in which class time is dedicated to exploring topics

in greater depth and creating meaningful learning opportunities, while educational technology such as online videos are employed to deliver content outside of the classroom. In a flipped classroom content delivery may take a variety of forms. Often, video lessons prepared by the teacher or third parties are used as a content delivery mechanism, though online collaborative discussions, digital research, or text readings may be utilized as well. In-class lessons accompanying flipped classroom may include activity learning or more traditional homework problems, among other practices, to engage students in the content.
Because of these characteristics, Flipped Classroom provides the theoretical basis for Peer Instruction applicability to distance learning.
To make Peer Instruction implementable with distance learning, the second point we have to answer is how to give students opportunity to interact remotely exact in the same way they would interact if they were in presence, i.e. physically present in a normal class. The solution is Virtual classroom, which represents a dedicated environment reproducing a real classroom and as well as any possible situation of a real class (Martini, 2014).
A Virtual Classroom is a multi-users environment and can be organized with different teaching aims. Most important, allows for multiple interactions mode (One-to-Many, Many-to-One and One-to-One). Today, there is a huge number of software permitting virtual classroom and more or less all of them are conceived like conferencing platform for web meeting. These kinds of software allow solving exercises together with students like in a real classroom and pave the way to a more personalized assistance.
All methods discussed so far need of a reliable way to check student understanding, which represents our last key ingredients to claim Peer Instruction applicability to e-learning courses. A widely diffused tool for testing the training level of students is the questionnaire, but the standard way of submitting tests to students has to be adapted to on-line delivered course. It should be an automated methodology to evaluate the effectiveness of the teaching/learning process. Each questionnaire should then be automatically generated from a large number of closed-answer questions.
This requires the creation of a wide database of Concept Test questions. It should also be preferable to have an automatically procedure to correct each questionnaire, which implies an analysis of the results based on a statistical model to assure reliability.
The literature on the subject is wide, anyway the method discussed by Professor Fabrizio Fontana, based on more than 10 years of data, has the advantage of affording not just the problem of the measurement of the degree of knowledge of a generic scientific subject in basic courses at academic level, but also the problem of the measurement of the effectiveness of the teaching activity of a single teacher for a given class (Fontana, 2005). Furthermore, Fontana's method is based on a statistical model that allows a quick correction of the questionnaires without any loss of information about the answer statistic of each single question. This enables the teacher to improve the data base of questions and to get a deep comprehension of which are the more difficult obstacles and "false friends" which are usually born during training. This aspect is crucial if one want to assure a more personalized student assistance, which is a feature difficult to implement in classical courses but much more easy to obtain when on-line courses based on modern technologies are considered.
Putting all this ingredients together result in a teaching model based on modern technologies that allow the use also of modern teaching method like Peer Instructions, as shown in Figure 2.
In this model, students watch theoretical lessons on-line and participate to on-line discussions trough Virtual Classroom. On-line discussions can be carried on using a Peer Discussion model and

student progress during the course is checked building up questionnaires from a wide database which include traditional problem solving exercises as well as Concept Tests. Each questionnaire is then corrected using a statistical model which allows to trace student progress, permitting to offer to each student a high level of personalized support and help.
First years of application show very interesting result and a general positive student response. Students have the feeling they are really learning how to manipulate equations, not just numerically, but also from a conceptual point of view. Moreover they receive quick and focused feedback to their errors, which address also their specific misconceptions and misunderstandings.

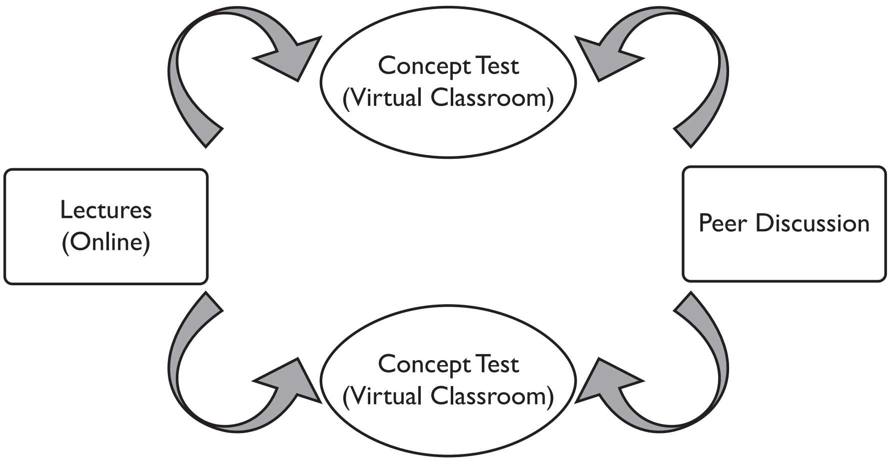

Figure 2. Peer Instruction schematic adapted to modern technologies for e-learning

Conclusions and perspectives

Flipping the Classroom plus Peer Instruction driven lessons can represent a valid and effective approach for e-learning, in particular for scientific courses.
Not all ideas may be applicable in any given setting, and by themselves these principles are not sufficient to make Peer Instruction work with distance learning courses. Yet, the level of understanding achieved by students is generally higher than the one obtainable with classical courses. Moving the theoretical lessons outside the classroom and encouraging students' discussion has numerous advantages.
The students' interactions and discussions break the unavoidable monotony of passive lecturing as students do not merely assimilate the knowledge presented in the lectures. On the contrary they are stimulated to think for themselves and encouraged to prefer an approach based on the understanding of the content of each lesson.
Moreover, the use of modern technologies for distance learning allows a more personalized assistance as every student actively participate to on-line discussions and solve periodically questionnaires whose results are automatically checked by a statistical method that permit to assess individual progress. Also teacher interaction with students improves, moving from sterile and passive lecturing to guidance for autonomous thinking.

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Sintesi

In un'epoca di rapidi progressi tecnologici, i tradizionali paradigmi di insegnamento vengono man mano sostituiti da nuovi metodi di formazione, all'interno di un nuovo progetto educativo basato sull'insegnamento a distanza. Questa nuova tecnica di formazione, utilizzando materiali didattici che si avvalgono dell'uso delle nuove tecnologie, informatiche e telematiche, offre la possibilità di rendere le lezioni più dinamiche e interattive. In particolare, l'uso di animazioni multimediali, simulazioni in tempo reale e laboratori virtuali risultano indispensabili per l'insegnamento a distanza di corsi scientifici, in quanto arricchiscono il patrimonio di informazioni e di conoscenza degli studenti e le loro competenze.

In questo contesto, con l'obiettivo di illustrare agli studenti ciò che realmente accade in un laboratorio di radiobiologia, è stato creato un laboratorio virtuale, con lo scopo di mettere in pratica ciò che viene appreso teoricamente e per rendere l'insegnamento e l'apprendimento più dinamici. Agli studenti viene fornita una parte teorica a supporto del prodotto multimediale che rappresenta la parte pratica.

La parte teorica introduce i concetti base della radiobiologia, approfondendo sui meccanismi di azione delle radiazioni ionizzanti sulla materia biologica e sui meccanismi molecolari attraverso i quali le radiazioni ionizzanti provocano effetti sulla salute (effetti cancerogeni e non cancerogeni) e descrivendo l'importanza della sperimentazione sugli animali che forniscono modelli per lo studio di patologie ad alto impatto sulla salute umana.

La parte pratica consiste in una simulazione interattiva dell'uso di un generatore di raggi X e di un modello animale radiosensibile. In particolare, il prodotto multimediale proposto, progettato sulla base delle attività di ricerca che si svolgono presso i laboratori di Biologia e Biomedicina dell'ENEA, ha l'obiettivo di essere utilizzato come strumento per migliorare le conoscenze e le competenze nel campo della ricerca radiobiologica. Utilizzando il prodotto multimedia, lo studente diventa autonomo e ha la possibilità di scegliere l'animale geneticamente modificato che vuole utilizzare, in base al tipo di effetto indotto dalle radiazioni ionizzanti che vuole indagare (medulloblastoma, carcinoma a cellule basali, opacità della lente e malattie cardiovascolari) e la modalità per indurre quell'effetto, selezionando diversi livelli di irraggiamento.

Il laboratorio virtuale è stato creato per consentire una più profonda consapevolezza della ricerca in campo biomedico e per offrire e promuovere una maggiore conoscenza scientifica. Questo prodotto multimediale verrà inserito come caso di studio nel corso Biologia Applicata e rappresenta un primo esempio di interazione tra e-learning e ricerca, fornendo agli studenti la possibilità di progettare un esperimento attraverso l'uso di varie tecniche di laboratorio.