VIRTUAL LABS FOR STEAM EDUCATION
LABORATORI VIRTUALI PER LA STEAM EDUCATION

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ABSTRACT

The interaction between artistic, scientific, and technological disciplines and the inclusion, in an interdisciplinary perspective, of art languages in science curricula is, today, in the field of education and didactics, at the basis of new methodologies and ways of constructing knowledge. In this paper we present some innovative teaching strategies developed in the field of educational research for improving STEM learning in a cooperative environment.

La relazione tra discipline artistiche, scientifiche e tecnologiche e l'inserimento, in prospettiva interdisciplinare, dei linguaggi dell'arte nei curricula scientifici è, oggi, nell'ambito della formazione e della didattica, alla base di nuove metodologie e modalità di costruzione della conoscenza. In questo lavoro si presentano alcune strategie didattiche innovative elaborate nell'ambito dalla ricerca educativa per il miglioramento degli apprendimenti STEM in un ambiente cooperativo.

KEYWORDS

Steam,virtual simulation, digital technology, scientific learning

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Introduction[1]

Since the introduction of the acronym STEM (Science, Technology, Engineering and Mathematics) into didactic-educational thinking, various approaches have been developed for teaching science with the intention not only of bringing children/youth closer to scientific disciplines, but also of increasing their problem-solving capacity and the development of transversal skills (Marone & Buccini, 2021). STEM subjects, in fact, are at the heart of vocational education and training, as their knowledge and mastery is considered essential for the development of the subject's agency and the formation of full citizenship (and it is also true that this contributes to increasing the level of national competitiveness, as well as providing solid training for access to the world of work) (Akerson & Buck, 2022). STEM competences, referred to as mathematical competence and competence in science, technology and engineering, are considered to be the decisive ones as they provide a solid foundation for tackling the technological and scientific challenges of the modern world and producing systems and solutions that meet the technical and practical needs of society through the stages of their design, implementation and management (Trinchero, 2012). To achieve this goal, it is essential to go beyond traditional education and revise teaching, adapting it to the technological and digital changes taking place that will be increasingly influenced by science and technology itself. Science education, already in the early stages of education, is a necessary link in the socialisation of science. However, focusing only on science, technology, engineering and mathematics is not always the most promising way to bring students closer to STEM careers. Creativity and the arts can, in fact, increase engagement and understanding in these fields, including the literary and artistic skills of trainees that can prove to be an asset in implementing the cross-curricular knowledge system and broadening critical perspectives. The STEAM approach represents a new educational paradigm that, based on real and authentic applications, enables the acquisition of intellectual and reflective, manual and creative skills, as well as technical, digital skills, combined with problem solving and computational thinking. In this perspective, the science-art-creativity triangulation is an ideal mix that, transformed into pedagogical approaches, allows scientific topics to be approached creatively, in a climate of constant dialogue, sharing and embodied experience within a physical and digital space (Varela et al, 1992). This grouping, which delineates areas of knowledge that are fundamental to the technological and scientific growth and development of society, has quickly

[1] L'articolo è il frutto del lavoro congiunto delle Autrici. Nello specifico, l'introduzione, il paragrafo 1 e le conclusioni sono da attribuirsi a Francesca Marone, i paragrafi 2 e 3 a Francesca Buccini.

become an international model for framing curricula that are more responsive to the demands of the labour market, under the banner of innovation thanks to the development of digital media. The STEAM methodology was therefore created to:

- Develop innovative teaching methods in Science, Technology, Engineering and Mathematics, with the addition of Art to enhance students' creativity;
- Stimulate the use of information technology, coding, making;
- Helping to overcome the gender gap by encouraging girls in the study of scientific disciplines;
- Developing innovative, interdisciplinary and intercultural methodologies, using Design Thinking for the design of teaching activities

It is thus outlined as an innovative educational method capable of leading learners, through the acquisition of intellectual, reflective, manual, creative, technical, digital, problem-solving and computational thinking skills, towards a deeper and more integrated understanding of the world around them (Yakman, 2008). Arts-based strategies, especially in interdisciplinary experiential learning contexts, create an inclusive and equitable environment, transform thinking, develop interest and confidence in learning, and nurture inclinations or interests to pursue STEM education and careers. Furthermore, the resulting learning environment influences the dynamic synergy between the modelling process and the mathematical and/or scientific content to be learned. Through this holistic approach, students are able to adapt their cognitive style and choose how to think and approach a problem in the most appropriate way. The STEAM perspective encourages students to think critically, solve problems and develop new skills, which are essential in an increasingly technological and globalised world. Based on these reflections, online laboratories were born out of the need to remedy the shortage of science laboratories in schools, offering a simple and inexpensive solution to problems of lack of resources and availability of equipment. The online lab can also be used as a preparatory environment for traditional school experiments, having the advantage of providing an initial familiarisation experience with active practice, thanks to gamification and edutainment, and constituting a valuable supplement to experiential work (Tho et al., 2017). Based on these reflections, online labs arise from the need to address the shortage of science labs in schools, offering a simple and inexpensive solution to problems of lack of resources and equipment availability. The results achieved in terms of skills are similar (Sypsas & Kelles, 2018; Wang et al., 2014) or greater than those achieved in traditional labs (Brinson, 2015;2017; Rubim et al., 2019). Moreover, the online lab can be used as a preparatory environment for traditional school experiments, having the advantage of providing an initial familiarisation experience to active practice, thanks to gamification and edutainment, and constituting a valuable supplement to experiential work (Tho et al., 2017). From this perspective, they can be used as a learning and support tool to improve students' conceptual understanding, knowledge and procedural skills as well as their motivation, without, however, completely replacing traditional experiments (Rubim et al., 2019; Udin et al., 2020).

1. STEAM, ICT and Virtual Learning Environments

Structuring a learning environment through the use of technological artefacts of various kinds increases the effectiveness of teaching processes by facilitating learning and the acquisition of new knowledge and skills (Cheng, Sun, Chen, 2018), as well as offering advantages over the use of traditional tools, as it can promote new meaningful ways of representing and knowing reality. Technology becomes a practical tool to research, learn, connect concepts, study, organise knowledge (Zdybel, et al., 2019) and apply what has been learned by interacting with it. These include simulations and digital games, which allow students to explore real or hypothetical phenomena in ways and at times that would not normally be possible in the classroom (Merchant et al, 2014); digital educational games (serious games) characterised by the presence of adaptive challenges through the emotional involvement associated with the results of actions performed, continuous feedback and sensory stimuli (Lamb et al, 2018); digital educational games, useful for knowledge acquisition, produce positive behavioural changes, are highly engaging and improve students' cognition and perception (central and peripheral visual acuity, selective attention and memory); mobile applications such as smartphones and tablets and mobile apps, designed for educational purposes; virtual and augmented reality, forms of immersive and multi-sensory technology that attempt to emulate a physical world through a digital or simulated environment, creating in the student a sense of immersion, more or less strong, in a reality that would not otherwise be possible to represent and investigate in the classroom; robotics and coding, useful for understanding programming concepts or for developing skills such as problem-solving, computational thinking, etc. Mastery of programming languages for computers and robots, including simple and versatile ones through digital games and interactive websites, can help students master technology and better understand how it works.). For this purpose, innovative teaching methodologies focusing on inquiry-based teaching and computational thinking are a resource for educational settings and a valuable tool for teachers, as they can improve the meaningfulness of learning and the attainment of transversal skills by students. Activities include the analysis of scientific questions through: identifying variables related to the problem to be studied, designing and carrying out experiments, interpreting data, developing explanations and communicating results and conclusions. Alongside traditional laboratories, the latest online laboratories also have the added value of conceptualising experience and reworking it through the juxtaposition of the real and virtual (Ranieri, 2011). The new educational requirements therefore call for the new technologies to be placed alongside traditional methodologies and paths, which, due to their characteristics of logicality, speed, modifiability, manageability and suggestive power, are undoubtedly a precise indicator of contemporaneity, the scientific foundation of a new way of exploring and traversing knowledge and different forms of knowledge. (Buccini, 2022). In contexts designed and organised in this way, through the exercise of observational, heuristic and exploratory skills proper to scientific practice, it is possible to initiate children into science, right from the early years of education. The two main online laboratory options can be distinguished into remote and virtual laboratories. The former can be defined as mixed virtual-real systems that allow students to carry out laboratory activities at a distance, interacting with instruments and/or components of a physical laboratory. The latter can instead be defined as entirely virtual (software) systems that allow students to interact with a digital environment to conduct simulated laboratory activities and/or manipulate digital representations of instruments and/or components of a physical laboratory. When we speak of laboratory education, although it is a strategy with a long tradition and strong pedagogical roots (think of the legacy left by educational scholars such as Pestalozzi, Dewey, Decroly, Montessori and Vygotsky), we often refer to experiences in school environments where students interact with materials to observe and understand the natural world from a Deweyan perspective. Such experiences can be very diverse in the way they are organised: individually, in small or large groups; with a very variable degree of structuring of activities by the teacher; with experiments and projects; with or without the use of digital equipment and have a number of advantages listed in the table (Tab. 1).

Improving subject mastery Develop scientific reasoning Understand the complexity and ambiguity of empirical work Developing practical skills	Understanding the nature of science Cultivating an interest in science and science learning Developing teamwork skills

2. Laboratory models and some didactic evidence

According to Hernandez- de-Menéndez (2019) analysis, remote and virtual labs can be thought of as complementary resources to be integrated into teaching and to be placed alongside traditional ones to provide meaningful learning experiences

TRADITIONAL LAB ADVANTAGES	*TRADITIONAL LAB DISADVANTAGES*
Enhances the physicality of the learning experience (direct manipulation)	*It encourages direct social interaction between students and between them and the teacher (in line with social constructivist theories of learning) High initial and maintenance costs Limits the number of students who can Conduct an experiment simultaneously Risks associated with improper handling of the equipment*
VIRTUAL LAB ADVANTAGES	*VIRTUAL LAB DISADVANTAGES*
Reduced equipment costs Several students can conduct an experiment simultaneously Models can be simplified to make complex phenomena more understandable It can enable students to observe and manipulate phenomena they would otherwise not experience No risk of damage to equipment Replicability of experiments Possibility of conducting certain experiments without the time constraints of natural processes	*Lack of physicality in the experience of learning Limited social interaction Risk of diverting attention to the simulation instead of the learning objective Limited fidelity of the digital representation of the natural world Reducing the learner's attention Student's attention in conducting the experiment and level of attention Simplification of models may limit understanding of the complexity of the natural phenomenon*
REMOTE LAB ADVANTAGES	*REMOTE LAB DISADVANTAGES*
Sharing skills and resources	*High set-up and maintenance costs*

Expensive/complex equipment and software can be used in different places *different locations* *Students in different locations can enjoy the same benefits*	*May be perceived by the student as unrealistic and associated with simulated laboratories*

In general, through online laboratories it is possible to perform experiments by In general, through online laboratories it is possible to perform experiments by overcoming the physical constraints of a school laboratory, interact with real equipment located in places other than where one physically works (remote laboratories) or observe and investigate various scientific phenomena in a simulated way (virtual laboratories). A review of the literature on the subject, which mostly involved secondary school students, shows that online laboratories can be used as a preparatory environment for traditional school experiments, having the advantage of providing an initial familiarisation experience with laboratory practice, thanks to gamification and edutainment, and of constituting a valuable supplementary experience to practical work (Tho et al., 2017). In terms of skills attained, in general, studies highlight the effectiveness of virtual laboratories and scientific simulations in increasing the ability to carry out scientific investigation understood as the ability to develop research questions, design experiments, acquire and analyse data, examine errors and synthesise results. They also show good levels in terms of problem solving, critical thinking, motivation and autonomous learning, as well as fostering an initial approach to experimental practices (Scalise, 2011; Sypsas & Kelles, 2018; Wang et al., 2014). Other studies have been concerned with comparing the learning outcomes of traditional and online (virtual and remonstrated) labs: almost all students provided evidence of equal or greater learning in the online lab than in the traditional ones. Students' level of knowledge and understanding, enquiry and analytical skills, and practical skills also present the same evidence (Brinson, 2015; 2017; Rubim et al., 2019). However, traditional laboratories cannot be replaced entirely. In this regard, Udin et al. (2020) show how the integration of virtual and traditional labs is more effective than traditional or virtual labs alone, as the former create a suitable environment for students' interactions and collaboration, while the latter implement, in the latter, the ability to engage in experimentation, increasing levels of self-confidence and motivation. Furthermore, when supported by appropriate textbooks and equipment, this combination facilitates the acquisition of new content. There is a multitude of teaching methodologies that can be extensively used with this approach; however, the most well-known ones both inside and

outside the classroom tend to favour participative, active and collaborative learning (Zacharia, at al., 2015).
In recent decades, the number of open-access simulations has increased exponentially. In addition to being highly versatile, these environments cover much of the essential scientific content in education (Wang et al., 2014; D'Angelo et al., 2016; Brinson, 2017); they are very flexible and intuitive and can be used simultaneously by several students. Moreover, the visualisation of and interaction with the simulated phenomenon studied can, if necessary, be repeated several times. These features make online labs useful resources for adapting and enhancing contextualised understanding of even the most complex scientific concepts and phenomena (Labdulhadi & Faisal 2021), as well as providing schools, professors and teachers with a valuable support to increase students' engagement and interest in science subjects. From anatomy to astronomy, from physics to chemistry, these environments help teachers to increase students' knowledge and skills, to inspire an interest in experimental learning methodology, to practically apply the theoretical concepts learned in class and to discover the laws that govern the world around us in a safe environment.
Online labs also offer a safe alternative to traditional labs for an engaging learning experience in the classroom and beyond. Creativity, light-hearted design, play and experimentation have been shown to foster learning and knowledge of STEM subjects. This will make it easier to introduce boys and girls to these fields from the earliest years of education. In fact, STEM-type activities are an extremely effective way of arousing interest, involvement and understanding of those subjects perceived as complex.

3. Didactic potential of simulation models: PHET (Physics Education Technology) Interactive Simulations

Educational simulations, defined as interactive learning environments in which the model simulates the characteristics of a system as a function of actions taken by the learner (Kirchner & Huisman, 1998), aim to develop understanding of the underlying model and the theoretical principles derived from it. It is possible to divide simulations used in education into two categories (Greca et al, 2014):
1) The virtual laboratories, used to observe on-screen phenomena under controlled conditions, manipulate variables and observe the effects of the manipulation;
2) Simulations of phenomena, used to model a system or process through the use of equations and the combination of objects with analytical, analogue and graphical representations.

Both have practical advantages such as safety, cost-effectiveness, the possibility of practising without space and time constraints, proceeding by trial and error and testing alternative hypotheses.

Free archives of digital simulations for education include, for example, PHET[2]. (Physics Education Technology). Interactive Simulations. PhET simulations are widely used in science education research and several uses can be found in the scientific literature (Fi. 1)

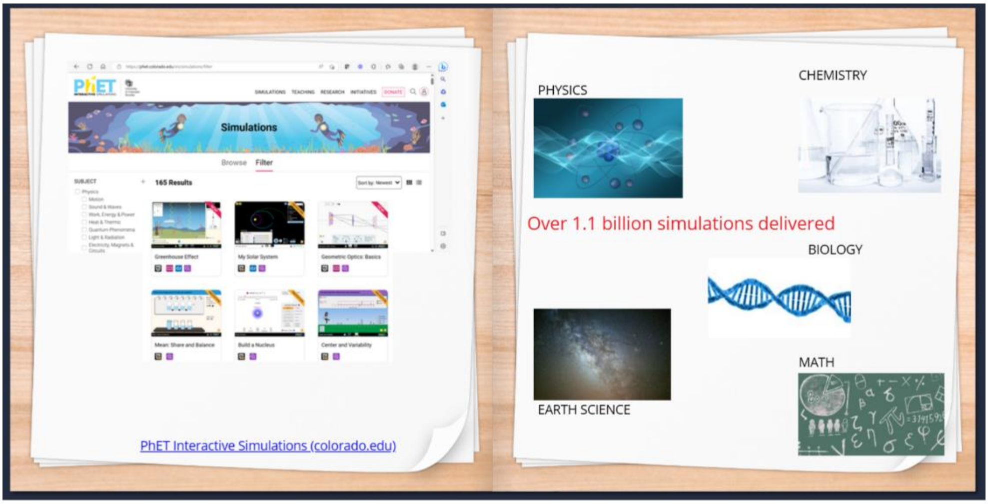

Fig.1 e-book made with Book creator, containing a selection of some STEM simulations

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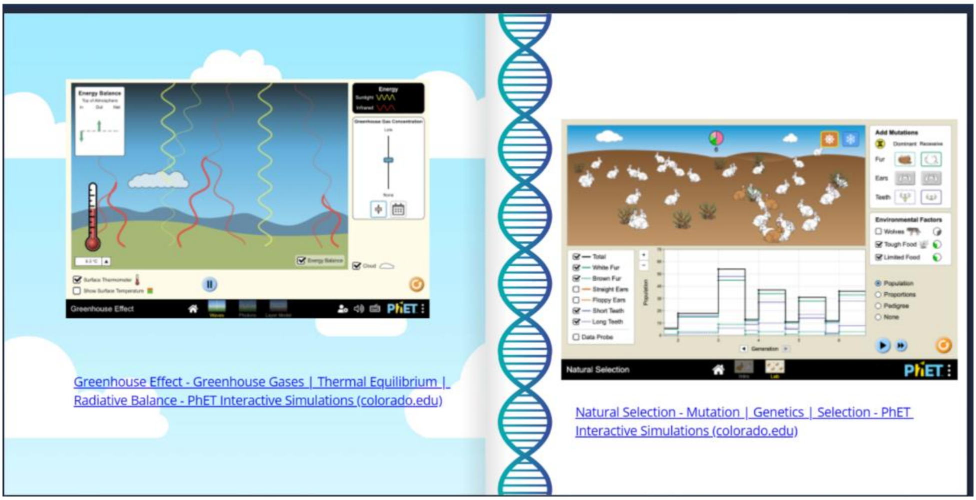
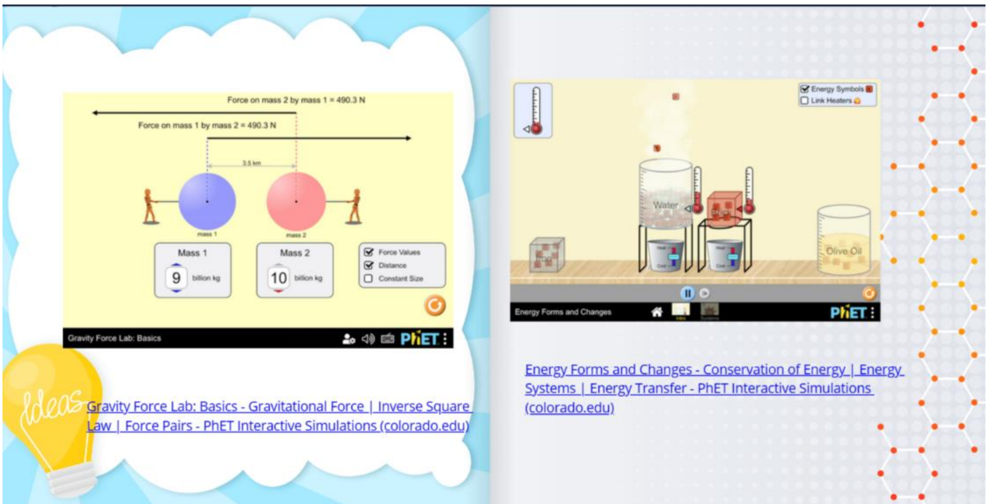
[2] Original version: phet.colorado. edu; italian verson by Vito Garganese: phet. colorado.edu/it)

PhET Interactive Simulations is a project of the University of Colorado Boulde, founded by Nobel Prize winner Carl Wieman in 2002 with the aim of improving science teaching and learning. PhET offers interactive science and mathematics simulations that have been tested and evaluated to ensure their teaching effectiveness. The simulations are written in Java, Flash or HTML5 and can be run online or downloaded to the computer (Fig. 2).





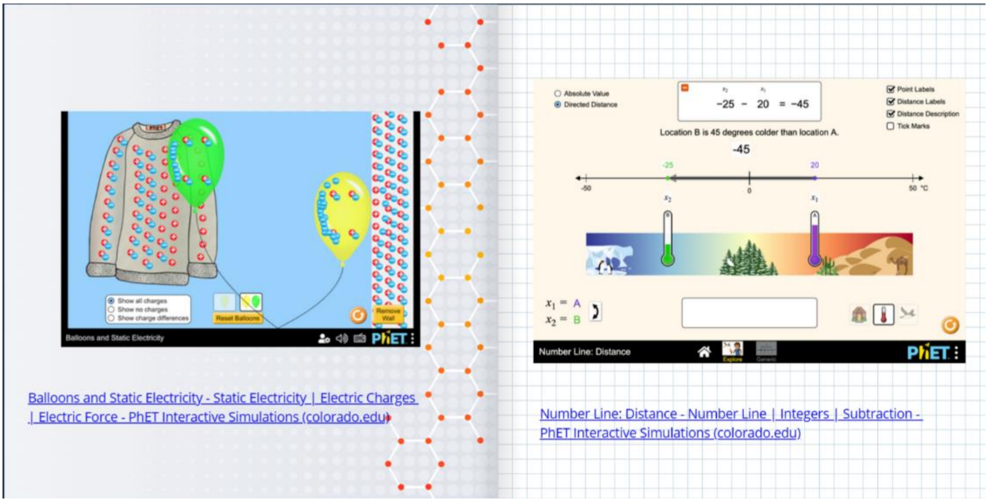


Fig. 2 Some examples of simulations in the ebook

All simulations are designed so that students can engage with science through enquiry, using the following design principles: encourage the scientific method; provide interactivity; make the invisible visible; visualise conceptual models; include multiple representations (e.g. object movement, graphs, values, etc.); link to experiences and phenomena; and provide a visualisation of the scientific method); link to experiences and phenomena; provide a visualisation of the invisible; link to real-world experiences and phenomena; provide users with guided pathways (e.g. control of limiting factors) in a fruitful exploration; create a simulation that can be used flexibly in different educational contexts (Wieman et al., 2010).

Conclusions

The comparison between online and traditional workshops, in terms of effectiveness and results achieved, makes it possible to identify some fundamental elements for promoting meaningful learning. These include encouraging active enquiry starting from knowing how to identify the research problem and develop hypotheses; observing and collecting data; stimulating the decision-making process, giving everyone their own time; giving space to evaluate plausible explanations of results, even unexpected ones; learning how to communicate, justify and discuss results, leading students to think like scientists (Scalise et al). These environments, inspired by Inquiry Based Science Education (IBSE), a methodology with an inquiry-centred approach, can stimulate the formulation of questions and concrete actions to solve problems and understand the phenomena under investigation (Harlen & Allende, 2009). Investigation is a multifaceted activity that involves making observations, formulating questions, examining textbooks and other sources of information to acquire what is already known, planning investigations, reviewing what is already known in the light of experimental evidence, using tools to collect, analyse and interpret data, proposing answers, explanations, and predictions, and communicating results. In this way, teachers can implement specific active learning strategies such as learning by doing, multidisciplinary approaches and methods, such as Inquiry Based Science Education (IBSE) and Technology Enhanced Active Learning (TEAL), which involve the design of collaborative and technological learning environments, the design of experiments, the presentation of case studies the creation of prototypes and problem-solving, also encouraging collaboration and group work (Zdybel, et al.2019). These good teaching practices contribute to fostering the development of students' cognitive, socio-relational, communicative, emotional-relational, technical-educational, and organisational areas, positively affecting the quality of inclusive processes (Romano, 2022).

In the context of digital didactics and with reference to online workshop-type activities, over the past decades, several studies, at both international and national level, have shown how skills and competences can be achieved through the proper mediation of technologies, even in online paths (Gutruf et al. 2021; Achuthan et al. 2021). However, digital didactics does not imply a mere transposition of the traditional lesson from the physical space to the virtual one and a digitised use of contents, form, and teaching methods. The design of such environments must not be identified with the adoption of ingenious didactic gimmicks, often unsuitable for activating the motivations of pupils and urging them towards a creative interdependence of their own development, but on the contrary, it must be a methodology that does not deteriorate into either the technicality or the instrumentalism that often deadens educational experiences (Harasim, 2000). The focus must therefore be on the quality of the design of the contents, which must be well structured, concise, interactive, and relevant, of the objectives and goals to be achieved. Since these considerations, it is important to ensure that teachers, especially of science and technology subjects, receive adequate training so that these experiences can be effectively integrated into everyday teaching practice. The experimental attitude required in these contexts outlines an active, constructive, collaborative, authentic and intentional didactic approach (Jonassen, 2008) capable of supporting traditional lessons by enriching them with contents of interest to learners (Hrastinski, at al., 2008) and to provide an educational and training offer that meets their needs, increasing their motivation to learn. Interactivity and the presence of collaborative spaces, graphic-visual communication, and the shift from a narrative structure of information to infographics, represent some of the main resources for the success of online lesson-lessons. A real methodological revolution that transforms the ways in which the learning experience itself is perceived, the perception of science and its relation to the real world and everyday life (Izzo et. al, 2018). The presence of motivated, expert teachers who are attentive to the needs of pupils is an indispensable factor in guaranteeing the learning subject the acquisition of strategies for decoding reality, encouraging their discoveries, and supporting their evolution, in learning terms, towards increasingly autonomous and conscious forms of knowledge (Rossi, 2011). The construction of suitable training paths and a constant mediation between models of representation of reality and stimuli from the environment enable knowledge to be processed, constructed, and transformed (Falchetti, 2007; Marone, Buccini, 2022).

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