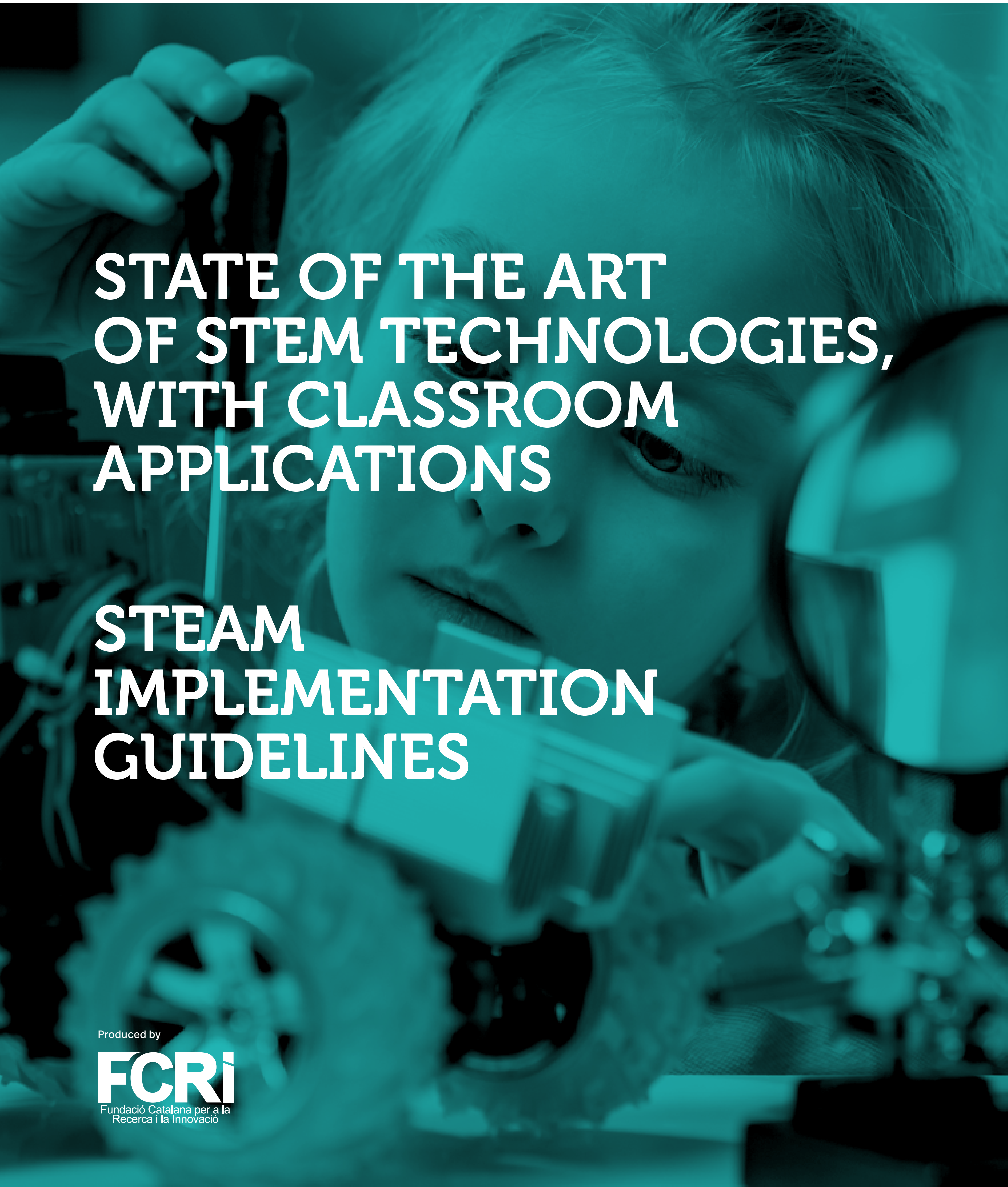
sySTEAM



STATE OF THE ART OF STEM TECHNOLOGIES, WITH CLASSROOM APPLICATIONS

STEAM IMPLEMENTATION GUIDELINES

Produced by

FCRI
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STATE OF THE ART OF STEM TECHNOLOGIES, WITH CLASSROOM APPLICATIONS

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INTRODUCTION

The main goal of the sySTEAM Project is to increase the educational use of STEAM (science, technology, engineering, art and mathematics), ensuring quality and the smooth implementation of inquiry-based, project-based, problem-based and transdisciplinary learning. This report, on the state of the art of existing and emerging technologies for classroom use, is the first step to achieving that goal.

The technologies featured in the present report span a sufficiently wide range of possibilities so that each school can identify the applications that best suit their needs. Technologies have been classified according to their degrees of maturity and development worldwide as either 'consolidated' or 'emerging', but all have been selected based on their capacity to mobilise transversal STEM projects.

For each technology, diverse aspects have been analysed: working principle, historical background, practical applications, educational connection and real-world examples. Our aim is to provide science teachers with a general outline on how to prepare pupils to be more creative, problem-solving and critical in the future.

This report will be followed by another presenting a set of guidelines to implement such technologies in the classroom.


CONSOLODITED
TECHNOLOGIES

PROGRAMMING

Programming skills have an impact on several key areas of citizenship development, such as ethics and critical thinking, problem-solving orientation, bridging the digital divide and improving labour market prospects.

With the participation of Jordi Losantos (Computer Engineer, Technical University of Catalonia (UPC); MBA, ESADE Business School; and secondary school teacher) and Joan Alemany (Graduate in Mathematics, UPC; cofounder, eSeeCode; and high school teacher).

Underlying principle

In computer science, programming refers to the action of translating a series of previously designed instructions (algorithms) into computer language in order to process a dataset for a specific purpose.

Any programming strategy requires prior modelling of the problem to be resolved from a perspective of applied informatics. This requires an in-depth analysis of the problem and a top-down design process that separates possible resolutions through automation.

Programming a computer application is based on logic, knowledge of sequential processes and the correct use of programming language syntax. Therefore, it is possible to write a programme without in-depth familiarity of the hardware used.

Historical background of programming

Programming was first developed in the 20th century in Europe and especially in the United States, with applications in the large electronic calculation machines of World War II (such as the large computer ENIAC). By the end of 20th century, microelectronics and the first high-level programming languages had emerged.

BASIC, Fortran and Pascal provide a reasonable interface, between a pseudo-human language and machine code. Today, the most commonly used programming languages – C++, JavaScript, Phython and PHP – include many functionalities that make it easy to write comprehensive computer programmes with few lines of code.

The latest trend in programming languages design is the minimisation of rigid syntax in the code, with very visual proposals generally based on interactive blocks that place more emphasis on the logical structure of the programme than on correct syntax. Scratch, Swift Playgrounds and GPblocks are good examples of this. Although they are widely use as teaching models, they are truly high-level languages that can be used to programme high-performance applications.

Practical applications in everyday life

Programming skills go far beyond the knowledge of some languages. Experts agree the most important idea is just the inherent adoption of computational logic, knowledge of technology and problem-solving analysis.

In a world where people are increasingly (and more intimately) interacting with all types of technological elements, from machines to software, programming knowledge provides the tools to effectively understand and use mobile devices, professional computing applications, social media, and even smart appliances, among other applications.

This last point is very important, as the current trend is to connect all types of devices, shaping a phenomenon known as the Internet of Things (IoT), which will pose great challenges for privacy and processing of personal data. Accordingly, it will also allow the development of technologies based on the analysis of large datasets, or Big Data, probably by means of artificial intelligence.

Thus, programming skills have an impact on several key areas of citizenship development, such as ethics and critical thinking, problem-solving orientation, bridging the digital divide and improving labour market prospects.

Educational connection

In the educational field, the need to teach the basics of computer programming to young people is as old as programming itself. One of the first systems adopted by schools was the Logo educational tool (designed in 1967), which has maintained its iconic turtle through various updates. However, some experts admit that under-investment in school computers due to the recession in the 1990s in Europe has kept programming skills from being integrated into the basic academic curriculum. It was not until the turn of the century, which coincided with a period of economic growth in Europe in 2004-2008, did computer programming return with force to the early stages of education. Lower hardware costs and good graphic performance have popularised Scratch (developed in 2015 and partially inspired by Logo) as the standard visual programming language. This programming system, based on manipulating interactive blocks rather than writing lines of code, avoids the frustration of having to write in syntax-dominated language and allows students to monitor the results of their programmes in any situation. In this paradigm, other languages (Swift, GPblocks, eSeeCode or Tynker) have emerged to improve some features that have not yet been completely perfected in Scratch.

At present, programming is included in the academic curriculum as a part of computer skills and new technologies at all stages of education in most EU Member States, and it is considered a key skill in the training of the future citizens. In particular, programming at the primary and secondary school level employs a series of cross-disciplinary skills in the educational development of children and young people, such as:

- critical and logical thinking;
- problem solving;
- implementation of strategies;
- analysis and evaluation of algorithms;
- abstract thinking;
- creative approach to reality; and
- teamwork (in large projects).

Practical examples

Experts agree that there is no single way to learn programming skills, and students develop them as the tools and task require. Therefore, creation-based approaches are fundamental. The concept would be ‘programming to learn’ rather than ‘learning to programme’.

CREATION OF SIMPLE GAMES

Programming games, from simple ones like Domino or Solitaire to more complex ones like platform games, presents students with multiple challenges to address by applying programming strategies based on problem analysis. These small games allow students not only to develop the programming part, but also artistic aspects (graphic design) and literary features (writing instructions for the player).

MAINTENANCE OF A WEBSITE

Many teachers in the STEM areas encourage students to maintain a joint class website, including a variety of information about the academic course. This can use various languages associated with the web, such as HTML, CSS, PHP or JavaScript, to integrate them into the site and provide it with a customised look. Of course, these activities also tackle aspects such as design, content writing and communication.

References

Alemany, J., Vilella, J. (2016). eSeeCode: Creating a Computer Language from Teaching Experiences. Olympiads in Informatics, 10, pp. 3 – 18. Available at: http://www.ioinformatics.org/oi/pdf/v10_2016_3_18.pdf

European Schoolnet (2015). Computing our future. [Online] All you need is code. Available at:
http://www.allyouneediscode.eu/documents/12411/67232/Computing/71653b80-4aa1- 4ca1-889d-23e9ad618f7d

Ford, Melissa (2017). Coding across the curriculum. [Online] Edutopia. Available at:
https://www.edutopia.org/article/coding-across-curriculum

ROBOTICS

Robotics applications in the classroom allow us to work on aspects that can hardly be addressed only by purely theoretical schemes.

With the participation of Jordi Losantos (Computer Engineer, UPC; MBA, ESADE Business School; and secondary school teacher) and Joan Alemany (Graduate in Mathematics, UPC; cofounder, eSeeCode; and high school teacher) and Frank Sabaté (specialised STEM teacher).

Underlying principle

Robotics is a transversal discipline that deals with the study, design, construction and application of robots. The terms robot and robotics have the same conceptual origin, although their adoption has a peculiar history.

Due to its multidisciplinary nature, robotics draws on many principles. On the one hand, it is based on programming, in the sense of coding the processes and actions for a robot. All information detected via sensor is processed from a computational point of view. On the other hand, since the robot is a physical device, its construction is focused on the basic principles of engineering, electronics and mechanics.

Historical background of robotics

Currently there is no unified definition of what a robot is. However, experts agree that a robot would be any engineering device, programmable by a computer, capable of collecting information from its environment via sensors and responding to it thanks to a set of automated actuators. It is, therefore, necessary to distinguish an authentic robot from automated software (popularly called bots) that would not be considered as robots even though it can be very sophisticated.

From a historical perspective, we can look back to legends from classical Greece or ancient China about the animated mechanical models of various animals, the golems from the Jewish tradition and even automatons: recreational pieces that were very popular in Europe in the 19th century. But these constructions lack an adaptive response to their environment
.
The term robot as associated with artificial creatures first appeared in 1920, in the play R.U.R. (an abbreviation of Rossumovi Univerzální Roboti) by Czech author Karel Čapek. In this play, the roboti (deriving from the Slavonic word robota: forced labour) are humans' artificial servants, who end up rebelling and extinguishing humanity. Although in Čapek's play those servants are not mechanical beings (today we would call them androids or clones), this moment marked the turning point when 'robot' was finally adopted as a modern version of the classic automaton.

Two decades later, the American novelist and professor of biochemistry, Isaac Asimov, coined the term robotics, first mentioning the neologism in the short story entitled 'Liar!' (published in the Astounding Science Fiction magazine in 1941), and using it widely in all his later literature, dedicated to exploring the limits of artificial intelligence and its impact on future human society.

Practical applications in everyday life

The EU report on robotics argues that developing robotics would have a positive impact in several areas:

- **Health**, with the development of assistive surgical devices and aid devices for elderly and/or functionally diverse people.
- **Agriculture and bioeconomy**, in automated sowing, harvesting and crop monitoring.
- **Energy savings**, developing more efficient and less polluting production systems.
- **Transport and retail management**, developing self-driving vehicles and automated warehouses.
- **Security**, in assisting and protecting citizens in risky situations such as rescues or assistance in extreme conditions.

Educational connection

In the educational field, turtle robots associated with the Logo programming language were first developed in the 1980s. Towards the end of the 1990s, the Lego company presented the Cybermaster robots, developed for use in schools, which were upgraded to Mindstorms NXT in 2006 and Mindstorms EV3 in 2013. As the need for electronic components has decreased, multiple options using all types of sensors with Arduino or Raspberry Pi technology have become available.

From an educational point of view, classroom robotics applications allow educators to work on aspects that can hardly be addressed by purely theoretical schemes. In this sense, translating formal concepts into reality is a major challenge for students because the robot's interactions with the real world force the programmer to deal with inaccurate data, variable stimuli and imperfect elements. That is why it is necessary to learn to design strong solutions for real problems in multidisciplinary projects.

Other positive aspects of using robotics in the classroom are more transversal, such as students' motivation, because they can perceive the practical and experimental approach as a game. Sometimes, students' interaction with the robot can be used to reinforce social aspects and skills. Robotics in the classroom help to bring technology closer to students, especially at a time when they are developing their strengths for the future.

Practical examples

ROBOT THEATRE

Robots ready to simulate human expressions, like Aisoy (https://www.aisoy.es), allow students to organise small plays with robotic actors. These would be designed to work with multiple skills such as the robot's programming, plastic expressions (clothing and props), performing arts, literature and human relationships.

PRECISION GAMES

Precision games have to do with programming a robot to cover a certain distance and be as close as possible to a mark or a wall. Students must give orders to the engine systems and optical or proximity sensors to decide when to stop the robot. This exercise shows students that reality poses more complex challenges than a theoretical treatment can solve, such as the uncertainty margin of sensors or loss of traction of the impeller device.

References

European Commission (2017). Follow up to the European Parliament Resolution of 16 February 2017 on civil law rules on robotics. Available at: http://www.europarl.europa.eu/oeil/spdoc.do?i=28110&j=0&l=en

REMOTE VIRTUAL LABS

In these simulated spaces, students can operate sophisticated and/or dangerous tools in safe conditions, facing the challenges of lab experimentation in a controlled environment.

With the participation of Sílvia Zurita (PhD in Chemistry, University of Barcelona; teacher, Polytechnic University of Catalonia; secondary school teacher).

Underlying principle

The scientific paradigm is largely based on the principle of empirical knowledge, so science education must include experimental elements. Many of these practical activities can be done in daily spheres, such as classroom demonstrations or field trips, but all educational establishments should have a properly equipped lab, dedicated exclusively to experimental sciences.

Equipping a lab is no easy task: scientific instruments are often expensive and fragile, and they may be toxic or dangerous if mishandled. Thus, well-trained teachers, flexible class arrangements that enable working with small teams, and adequate funding are needed for setting up and running school science labs. Even with these conditions in place, many concepts cannot be tested due to obvious limitations, such as the study of nuclear reactions, explosive combustions or molecular genetics. But lab competence is a growing demand in the EU labour market, which is increasingly focused on research and innovation.

Fortunately, technological developments have enabled the creation of interactive and often sophisticated simulations, as an authentic virtual lab. In these simulated spaces, students can operate sophisticated and/or dangerous tools in safe conditions, facing the challenges of lab experimentation in a controlled environment.

In addition to virtual lab realities, there are also remote labs: physical premises that can be remotely operated to obtain real experimental data. Remote labs have the advantage of showing all the imperfections of real life, something difficult to programme on a simulation, but there are very few and their activities are quite limited.

In order for a virtual or remote lab to be effective in an educational context, they must appeal to students. That is why the current trend is to use elements of virtual and augmented reality as well as gamification. The aim is to transform a static activity in front of a screen into an immersive experience that pursues a stimulating objective.

Historical background of virtual and remote Labs

VIRTUAL LABS

It is not easy to trace the history of simulation as an educational tool. However, we do know the first simulations were made using physical elements, for instance the dolls used in the 1960s in medical schools for lung resuscitation practices.

The popularisation of computers in the 1980s, together with the appearance of high-level programming languages, allowed the first simulations of virtual reality, especially for the flight simulators widely used in the flying schools. Those simulations reached the general public through games such as Microsoft's pioneering Flight Simulator (1982). In 1989, Maxis launched the first edition of Sim City, an urban simulator, followed by Sim Earth (1990), a planetary simulator with a rudimentary system of climate and ecological control. Universities also developed virtual applications to complement their studies, usually free of charge, but their specificity, high level and the impossibility of mass distribution limited their application elsewhere.

The year 2004 marked the advent of the so-called Internet 2.0, characterised by greater social interaction and the popularisation of broadband. Internet became much more accessible, and applications developed in university environments could be more easily disseminated online. Many of those applications transcend the university environment and have an impact on simple concepts covered in primary and secondary school. Given the continuous updating of these virtual spaces, it is difficult to establish timing. Thus, a (non-comprehensive) review of the current accessible virtual labs will be carried out in the following sections.

REMOTE LABS

As in the case of virtual labs, the history of remote labs is also opaque. The fact that many of these initiatives are limited to the university sphere make them difficult to find and, in many cases, difficult for novices to operate.

Research into remote labs did not uncover platforms dedicated to their dissemination or broad repositories.

Practical applications in everyday life

Virtual labs are designed as an educational complement, so everyday applications in people's lives derive from their contact with such applications at school and/or university. Thus, the direct benefits of this technology would be the same as those of the physical lab, namely:

- Implementing research methodologies in daily life. A paradigmatic case is the emergence of a new cuisine, greatly influenced by laboratory-based techniques.

- Enabling outreach activities. While many such activities are designed for formal education, they open the door to science teachers using them in all kind of activities, such as conferences or workshops.

- Encouraging critical thinking. The opportunity to undertake realistic activities in a research environment, even if it is a simulated environment, allows us to understand the complexity of scientific methodology and to combat the proliferation of simplistic, pseudo-scientific ideas.

Educational connection

In the classroom, virtual labs provide a great opportunity to work on various aspects of the academic curriculum as well as cross-cutting skills. In many cases, the resources used in these systems allow people to mentally visualise processes that would be difficult to transmit otherwise. However, consulted experts stressed the need for highly specialised and trained teachers to give these tools real educational meaning.

In the curriculum section, we have already mentioned that virtual labs enable experiments that cannot be carried out in a school lab due to hazard or cost (nuclear exploration or genomic techniques, for example).

But we can also find some very remarkable elements in the cross-cutting skills area:

- Students' motivation. Gamification and 3D immersion strategies used in modern virtual labs enhance the attention and retention of students who may be less receptive to traditional scientific practice. This trend is increasing because of the development of new systems of sensory interaction with virtual reality, such as touch or smell.

- Socialisation and interaction. Groups of students should soon be able to interact in the context of virtual labs, assuming different roles and working together to carry out research.

- Familiarisation of digital environments. Performing an activity in a virtual environment can attract students to these technologies and inspire future developments in the field of virtual or augmented reality.

In any case, and without underestimating the utility that these tools can have in an educational centre, it is important to stress that these tools complement school labs, which cannot be abandoned.

Practical examples

VIRTUAL LABS

There are a number of virtual labs online. Many are simple, open-access simulations or interactive animations on a specific topic. Others are genuine labs, designed with virtual reality technology, which replicate fully equipped professional facilities. In line with the criterion of Lynch & Ghergulescu (2017), here are a few examples:

2D labs based on web technology (HTML5 or JavaScript):

- **Go-Lab Project** (https://www.golabz.eu), now known as NextLab, is a web portal funded by the EU under the scope of the Horizon 2020 programme, dedicated to inquiry based science education (IBSE). Their school labs feature numerous interactive activities focused on different aspects of science, as well as a tool for teachers to design and share their own virtual labs, adapted to their context.

- **ChemCollective** (http://chemcollective.org/home) is a repository of virtual labs in the field of chemistry, which are programmed in HTML5 and can be used in nearly all current browsers.

- **NMSU Virtual Labs** (http://virtuallabs.nmsu.edu) is a web portal of the New Mexico State University. Users can work several aspects of food science and technology on their virtual labs.

3D virtual labs based on virtual reality systems:

- **3D Labs UPM** (https://3dlabs.upm.es) is a project of the Technical University of Madrid that has several virtual labs. Experiments are focused on engineering, physics and chemistry. Activities are performed in 3D virtual reality environments and designed using open-source software called OpenSim.

- **Virtual Engineering Sciences Learning Lab** is a virtual space created in the SecondLife platform, where users can perform activities in an environment designed as a science museum. Users' interaction provide an extra layer of social skills, which is less visible in other virtual labs.

- **Labster** (https://www.labster.com) offers a fully equipped 3D virtual lab for all kinds of experiments in molecular biology and chemistry. As it is a private initiative, its services are subject to user charges.

REMOTE LABS

- **Faulkes Telescopes** (http://www.faulkes-telescope.com) is a network of robotic telescopes, used by students and teachers for free. Anyone can book a time to operate one of the many telescopes throughout the world to obtain real astronomical images and use them in the classroom. The fact that there are telescopes in many locations allows teachers and students to observe the night sky during class time.

- **VISIR** (http://ohm.ieec.uned.es/portal/?page_id=76) is an automated breadboard where electronics student can remotely test the result of a real wiring.

References

Lynch, T., Ghergulescu, I. (2017). Review of Virtual labs as the Emerging Technologies for Teaching STEM Subjects. In: *11th International Technology, Education and Development Conference* [online] Valencia, Spain: Newton Project: pp.1–10. Available at: http://www.newtonproject.eu/wp-content/uploads/2016/02/review-of-virtual-labs-as-the-emerging-technologies-for-teaching- stem-subjects-1.pdf

EDUCATIONAL VIDEO GAMES

... games may activate important social mechanisms, such as problem solving, empathy and teamwork ...

With the kind participation of Víctor López (physicist, PhD in science teaching; researcher, CRECIM- Universitat Autònoma de Barcelona (UAB); associate lecturer, UAB) and Cristina Simarro (researcher, CRECIM; industrial engineer; associate lecturer, UAB).

Underlying principle

A major trend in education nowadays is gamification, or the use of game strategies such as earning badges, points or other rewards after completing particular tasks in the classroom, as a means to motivate and engage with students in their learning process.

Game-based learning (GBL) is another, slightly different concept, wherein board games, card games, video games or other game formats are used to actually learn and practice the subject material, not just to motivate students.

Both strategies can improve classroom dynamics and be implemented both on- and offline in different ways. However, this report focuses on the technological side of gaming and reviews only educational video games.

The main principle behind gamification and GBL is based on the stimulation of a dopamine rush. Dopamine is the neurotransmitter used by the brain for motivational purposes (in a very simplified way). Every action with a sense of purpose, especially those with an expected positive reward, are driven by dopamine and result in the activation of the pleasure centres of the brain once the action is accomplished.

Thus, as long as the challenges and the rewards offered are meaningful to students, gamification and GBL can improve their concentration and increase the time spent on the subject. And this is a key point in the success of any of these strategies, since the game by itself cannot force children to learn. A well-planned, teacher-driven educational process behind gamification and GBL is paramount.

Historical background of educational gaming

Although some argue that Pac-Man was the first educational video game, its intention was purely entertainment. However, Pac-Man applied many characteristics of an educational game, such as simple rules, obvious rewards, a sense of excitement and puzzle solving.

Many regard the first educational video game to be the Logo programming environment (1967). While it may not have been intended as a game, the act of moving the tiny turtle around by coding instructions on the console was indeed entertaining. And many schools used it (and still do) to teach the fundamentals of computer thinking and mathematical concepts in a fun way.

With the popularisation of home computers came the emergence of the video games industry, and the educational area was just another market to be exploited. 'Lemonade Stand' (economics), 'Oregon Trail' (History), 'Reader Rabbit' (Language) and 'Where in the world is Carmen San Diego?' (Geography) were some of the first video games created for educational purposes in the 1980s. Some became very popular, especially in the United States.

As computer performance increased in the 1990s, video games became more interactive and complex. Many games simulated realistic environments, like Sim City, Sim Earth, Civilization and several kind of flight simulators, exploiting the basics of virtual reality. However, in time, a number of these evolved into arcade games, and their original educational aims were lost.

In the late 1990s and the 2000s, home consoles overtook personal computers as the device of choice for most video games. PlayStation, Xbox and Wii released educational games like Brain Academy or MineCraft as a means to attract a family audience, not just the usual teenage gamers.

Since 2007, with the introduction of the iPhone and the popularisation of mobile devices, most educational games have been transformed into Apps. Today, thousands of educational games can be found on iTunes and Google Play, and many are used daily at schools all over the world.

Practical applications in everyday life

A game can be described as an artificial conflict between players that must be solved by using a set of predefined tools and rules, agreed on by everyone. Thus, depending on the game, important social mechanisms can be activated, including problem solving, empathy and teamwork.

In 1786, Benjamin Franklin published an essay entitled 'The morals of chess', comparing chess game with real life. In the text, he outlined how a chess player learned important social values, such as perseverance, foresight and caution, through the game playing.

What Franklin stated for chess is true for video games as well. In 2013, a team of Dutch researchers published a review of research on the benefits of playing video games, reporting evidence to support the idea that modern video games develop a set of important skills, from spatial recognition to social interaction.

On the other hand, playing video games at school might put people in contact with computers from an unexpected perspective. Kids who are not especially attracted to technology might develop computer skills and become familiar with virtual or augmented reality, whereas they wouldn't otherwise.

Educational connection

Most of the educational connections described for virtual labs also apply to video games.

In the field of STEM-based video games, however, experts agree on the importance of engaging students in activities showcasing scientific practice. In this regard, gamified virtual labs, embedded into a virtual reality environment, would be the best approach from the educational perspective.

Quiz games have become quite popular in recent years, especially since the introduction of mobile platforms. Many are tagged as 'educational apps' in Google Play or App Store, but they lack a relevant educational impact since their focus is content that the player already knows, with no opportunity to practice new skills.

This notion is consistent with the idea of 'learning by doing', and one must keep in mind that indeed, video games can help people practice and acquire some basic concepts, but interaction with a teacher is still necessary to fully understand the details of the subject material.

Thus, provided there is a teacher with a well-defined plan, gamification and GBL can help with the motivational side of learning in the classroom and can be used as a means to practice and consolidate some lessons.

Practical examples

- **Learn Science** (Nintendo DS). In this game for handheld Nintendo devices, the gamer can play minigames based on diverse aspects of science. The progress is mainly practical, with demonstrations and puzzles to be solved, and the player can obtain rewards. There is a social side too, since players can challenge their friends online for better scores.
- **Food Fight** (any platform https://www.brainpop.com/games/foodfight). Food Fight is a simulation of an ecological web chain for two players. Each gamer takes the role of a species and tries to increase its population, while jeopardizing their opponent's success.
- **Spore** (PC, Mac and Nintendo platforms). Design a creature and develop it through different evolutionary stages, from cell phase to full civilisation and space exploration. Each stage lets players explore and modify the fundamentals of the universe at their will.
- **Manga High** (any platform: https://www.mangahigh.com/en). Somewhere in between gamification and game-based learning, this programme offers teachers several minigames in the field of mathematics and geometry, with the possibility to assign and schedule tasks to the students.
- **Blood Typing Game** (any platform: https://www.nobelprize.org/educational/medicine/bloodtypinggame). Simple web-based game to practice the basis of blood types and blood compatibility between people. There is some resemblance with clinical practice, with needles and tests and transfusions into patients. The player must possess some previous knowledge on blood types to play successfully.

References

Granic, I. et al. (2013). The Benefits of Playing Video Games. American Psychologist, [online] 69(1), pp. 66 –78.
Available at: https://www.apa.org/pubs/journals/releases/amp-a0034857.pdf

Needleman, A. (2017). A quick history of educational video games. [online] Gamer Professionals.
Available at: https://www.gamerpros.co/education-and-video-games.

Zhen, J. The history of educational video gaming. Immersed Games.
Available at: http://www.immersedgames.com/the-history-of-educational-video-gaming.

LOW-COST EXPERIMENTATION

...the idea that anyone, anywhere, can perform the experiment encourages students to try it at home with their families. The thrill of experimentation may awaken new vocations for science.

Underlying principle

The basic grounds for low-cost experimentation is to make science popular. The idea that science is an activity, rather than a set of facts or concepts, implies that anyone, anywhere, should be allowed to experiment with the rules of nature.

The downside of this challenging idea is that expensive lab materials are sometimes needed to see an effect. Thus, low-cost experimentation refers to any procedure by which anyone can test fundamental aspects of science at virtually no cost by using common materials.

Historical background of low-cost experimentation

Low-cost experimentation might be considered an evolution of the do-it-yourself (DIY) movement that arose in the United States in the early 20th century. This concept reached maturity in the 1960s Bay Area punk scene. The original DIY movement wasn't about explaining the science behind natural phenomena but rather using a countercultural approach to reject consumer society. However, as the projects grew in complexity, engineers from various fields started sharing their technical knowledge with the rest of the DIY community.

The popularisation of science, as we know it today, began in the mass media. Its peak can be considered the broadcast of the mythical series Cosmos, a Personal Journey during the fall of 1980. The show, created and presented by Carl Sagan, reviewed the history of the universe, the evolution of species on Earth and the success of mankind in the search for knowledge. But Cosmos was a story about science, not science itself.

One of the first science shows on TV with hands-on activities was the 1992 Beakman's World. Inspired by a 1991 comic strip by Jok Church and targeted to a fairly young audience of pre-teens and adolescents, Paul Zaloom played the role of an extravagant scientist demonstrating various physical and chemical curiosities. Most of the experiments were designed in such a way that anyone could repeat them at home with basic raw materials. In fact, do-it-at-home was actively encouraged.

Since then, many science shows have been produced all over the world with similar formats.

Practical applications in everyday life

The idea that anyone can test the basic rules of the natural world is challenging by itself. The empirical knowledge of how things behave may make a difference to anyone and promote basic science literacy to non-scientists.

Thus, the design and development of low-cost experiments (and their proper dissemination) can contribute to promoting more rational, less superstitious and more critical societies.

Educational connection

Schools tend to be under funded, so any experiment performed with common materials such as those found in a school or a local hardware store is very welcome. Besides, the idea that anyone, anywhere, can perform the experiment encourages students to try it at home with their families. The thrill of experimentation may awaken new vocations in science.

On the other hand, experimentation tends to be multidisciplinary, and many of the experiments that can be done with common materials develop concepts from many subjects, such as physics, chemistry, biology, mathematics and technology. Building bridges across disciplines at school makes classes more dynamic and appealing, boosting motivation.

Moreover, most of the materials used for experimentation are recycled or reused, such as empty plastic bottles or used straws, so engaging the students in planning and performing these kinds of experiments reinforces their sense of sustainability.

Practical examples

- **Reaction car** (https://explorable.com/balloon-rocket-car-experiment): using a plastic bottle, a balloon and a straw (and a couple more things), anyone can build a car that moves using Newton's 3rd law of kinematics.

- **Plants see the light** (http://www.untamedscience.com/biology/plants/phototropism): plant some seeds in a box with a small opening in one side and wait for them to sprout. In a few days you will see how the seedlings reached the opening regardless of any obstacle in their path. This experiment might show you one of the properties of any plant: phototropism.

- **Mentos geyser** (https://www.stevespanglerscience.com/lab/experiments/original-mentos-diet-coke-geyser): If you drop a Mentos candy into a soda, the tiny pits on the surface of the candy will serve as nucleation points for the dissolved CO_2. The rapid formation of bubbles at these points makes the whole bottle burst with a powerful stream. This is an adaptation of the classic experiment with baking soda and vinegar, but the principle behind it is much different.

References

Fandom. *The do it yourself Wiki 'DIY Culture'*. [online]
Available at: http://diy.wikia.com/wiki/Do_It_Yourself. [Accessed April 2018].

EMERGING TECHNOLOGIES

3D PRINTING

3D printing should be considered a productive tool for all subjects related to design.

With the participation of Joan Alemany (graduate in maths, Politechnical University of Catalonia; co-founder of eSeeCode; secondary school teacher) and Frank Sabaté (schoolteacher specialising in STEM).

Underlying principle

3D printing is the group of processes allowing the manufacture of physical objects from a computer model, using computer-aided design (CAD) or a 3D scanner.

This kind of printing can be classified under the additive construction paradigm, whereby the piece is the result of positioning the modelling material, layer by layer, until the final product is complete (like in the construction of a building). In contrast, subtractive construction implies casting an initial piece and then cutting away excess material until achieving the final product (like in classical sculpture).

To achieve this additive effect, 3D printers must be automatic and programmable tools that use semi-solid or solid materials to work with volume, not only on surfaces like a traditional printer.

Therefore, 3D printing draws on computing and programming principles that allow the development of 3D, computer-aided design, as well as on mechanical and engineering elements that enable the manufacture of 3D printers themselves.

Historical background of 3D printing

The main 3D printing systems were first developed in the 1980s by Dr Hideo Kodama, from the Industrial Research Municipal Institute of Nagoya, in Japan. Kodama developed the precursor to the current stereolithography system (SLA). The first patent for this system was granted to the American inventor Charles Hull in 1984; Hull brought the first 3D printer based on the SLA-1 3D system to the market in 1987.

A year later, in 1988, Carl Deckard filed a patent for the SLS, a new way of 3D printing based on the fusion of dust particles. In 1992 the Stratasys firm marketed the first printer based on fused deposition modelling (FDM), which became the standard for the most popular 3D printers for amateurs because of its low cost.

Nowadays many firms are testing the limits of these basic technologies with new systems to work and combine different materials, like metals, and to increase printing speed.

Practical applications in everyday life

Professionals and experts generally agree that 3D printing will shake up the productive sector at an international scale. Logically it will also transform the global economy.

Although it is difficult to say with certainty what the future holds, the potential for manufacturing practically any object, using a broad range of materials, could culminate in a situation whereby consumers would be able to print most daily products at home rather than buying them in physical shops. The end user of a product would purchase the design directly from big online shops and load the design onto their own printer.

From this point of view, the practical applications of 3D printing in daily life would be endless.

Educational connection

The above-mentioned implications in daily life depend on consumers' capacity to produce most basic consumables locally. There is thus no need to learn but only to choose from the diverse models on the market.

From an educational perspective, however, 3D printing poses an interesting challenge. The consulted experts are worried about the current trend of avoiding the use of 3D printing capacities as learning tools in favour of using them solely as demonstration. As a consequence, downloading pre-designed models of the most popular repositories like OpenSCAD (www.openscad.org), Tinkercad (www.tinkercad.com) or Beettle blocks (beetleblocks.com) is not regarded as an authentic educational application of these technologies. Hence it is essential to establish clear teaching objectives before starting 3D printing activities in the classroom.

3D printing should be considered a productive tool for all subjects related to design, for instance:

- Engineering and technology: production of objects and construction of models or mechanical or electronic devices previously designed in the classroom.
- Mathematics and geometry: spatial visualisation of shapes and abstract figures obtained from theoretical processes.
- Plastic and artistic expression: design and production of theatre props and three-dimensional art objects.

Practical examples

There are diverse 3D printing technologies, each with its own strengths and weaknesses, depending on the intended use of the printed object. The most common examples are:

- **Stereolithography (SLA):** the original material is a viscous liquid that solidifies when exposed to intense ultraviolet radiation. The model is constructed inside a container filled with this material and with a motorised platform. A laser emits a beam of ultraviolet light with the shape of the first (interior) layer of the figure, thus fixing the first sheet. The platform goes down to dip the model in the material again and afterwards the second layer is radiated and joined to the first, and so on until the model is completed.

  The main advantage of SLA is its speed and the level of detail that can be achieved. Nonetheless, the models are fragile and sensitive to direct sunlight.

- **Selective laser sintering (SLS):** from a mechanical point of view, SLS is similar to SLA, but the original material in SLS is a powder, usually made of nylon (though it also can be from other materials like polystyrene or ceramic). The laser heats up the first layer of the powder, fusing the particles. The motor platform immediately lowers again, and a fine powder is brushed onto the model, constituting the second layer. When the model is complete, the remaining nylon power is extracted with pressurised air.

  The main advantage is that the fused nylon is very resistant, so the pieces made using this technique can be functional. Besides, since nylon powder is solid, there is no need for printing support structures in the model.

- **Modelling through fused deposition modelling (FDM):** there are different ways to apply FDM, but in general, the initial material is a solid plastic thread which is heated up until the fusion point and settled in layers by an extruder capable of moving in space. The process usually proceeds from the bottom up.

  Since all the components are basically mechanic, without lasers or sophisticated elements, FDM is the least expensive solution and thus more accessible to non-professional users. However, the quality of the models is inferior to those produced by the SLS and SLA systems because the thickness of the thread determines the resolution and the maximum detail that can be achieved.

References

Bensoussan, H. (2016) The history of 3D printing: 3D printing technologies from the 80s to today. [online] Sculpteo.com. Available at: https://www.sculpteo.com/blog/2016/12/14/the-history-of-3d-printing-3d-printing-technologies-from-the-80s-to-today

The Economist, (2017). 3D printers start to build factories of the future. [online] Available at: https://www.economist.com/news/briefing/21724368-recent-advances-make-3d-printing-powerful-competitor-conventional-mass-production-3d

OPTICS AND PHOTONICS

... there is no easy way to teach the nature of light and its properties ... understanding light is non-intuitive, so it must be taught with very carefully and with an educational plan in mind.

With the kind participation of Víctor Grau (PhD in physics; Professor, Arts and Sciences Teaching Department, Universitat de Vic).

Underlying principle

Optics and photonics are closely related branches of physics that study light and its behaviour. Optics can be considered the traditional framework from which photonics emerged upon discovery of the quantum nature of light.

Briefly, light can be understood as an electromagnetic wave and a beam of tiny particles called photons. From the perspective of a wave, light moves through space in the form of a wavefront that can show classical properties such as reflection, refraction, diffraction and interference. Its wavelength (the length between peaks expressed in nanometers) accounts for its colour.

However, light is much more complex than that and should not be represented as a typical mechanical wave, as it appears in many textbooks. Physical and geometrical optics explain and predict many of the classical properties of light in great detail.

From the perspective of a beam of photons, light shows properties not seen in classical waves, such as a photoelectric effect, accounting for individual impacts of photons on a detector, or the light produced in an LED device, where electrons release a photon when falling into lower energy states. This new perspective led to the emergence of quantum optics and related fields.

Historical background of optics and photonics

There is some controversy about when optics became a field of study. A 3000-year-old lens-like object was found in Nimrud (today's Iraq), suggesting that optics were first studied in the Assyrian culture. However, there is no consensus on whether it was actually used as a lens or if it was just a piece of furniture.

We know for sure that the ancient Greek and Roman cultures used glass spheres filled with water as lenses and developed some theories on the propagation of light. In fact, the term optics comes from the ancient Greek optikē, meaning appearance. After the fall of the Greek and Roman civilisations, the development of optics continued in the Arab and Indian worlds, with key documents on the field capturing the knowledge gained.

It is noteworthy that the earlier theories did not represent light appropriately, and while they described properties like reflection or refraction with some detail, they failed to understand what could emit light and how images were formed in our mind. In this regard, the initial development of physical optics was grounded on a deficient understanding of the fundamentals of light itself.

As an example of this misunderstanding, the 17th century saw bitter discussions between Newton and Hooke, two of the most renowned physicists of all time, on the nature of light as either a bundle of particles (according to Newton) or as a wave (according to Hook). Both interpretations were based on Kepler's earlier works on geometric optics. Needless to say, both were partly right in their assumptions.

The 19th century saw the first steps in the resolution of the conflict, with Young's and Fresnel's experiments definitively establishing the nature of light as a wave, and later, with the Maxwell equations showing light from the electromagnetic point of view.

In the 20th century, Planck, Einstein and Bohr completed the theory of light as both a wave and particle, planting the seed for a new field: quantum optics. The invention of the laser in 1960 is regarded as the starting point of photonics, dealing mainly with the study of photons, its physical properties, its production and its interactions with matter.

Practical applications in everyday life

Humans are diurnal creatures, so light is all around us most of the time. We often make decisions based on optics, for instance painting a room with light colours to maximise illumination or considering the position of the windows when installing a TV in a living room to avoid reflections. However, many of these decisions are based on an intuitive understanding of basic optical phenomena. And optics can be tricky sometimes.

A solid understanding of light and its properties might be of use in our daily life in many aspects:

- Photography and video, especially considering the widespread use of smartphones and photo/video sharing apps.
- Use of light-based devices, such as remote controls, motion detectors and proximity sensors.
- Identification of optical effects, such as mirages or other distortions due to reflection and refraction of light.

Educational connection

According to experts, there is no easy way to teach the nature of light and its properties. Introducing it in the school curriculum would require starting with the particle-like model in primary school (6–12-year-olds) and proceed to the wave model during secondary school (12–18-year-olds).

The obvious connections between optics and photonics are rooted in mathematics, physics and technology, the core STEM disciplines. However, there are other connections:

- **Biology**: optics and photonics help explain the basis of photosynthesis in plants, the colour of flowers and the physiology of the eye.

- **Philosophy**: the very idea of seeing may raise some philosophical questions, such as the subjectivity of beauty.

- **Arts and humanities**: many artistic expressions depend on light, including photography, painting, architecture and performing arts.

Practical examples

One of the most important issues raised by the experts when it comes to teaching optics and photonics is the notion that understanding light is non-intuitive, so it must be taught very carefully and with an educational plan in mind.

No simple practical example or analogy can explain light, so teachers are strongly recommended to first build up a solid knowledge of the fundamentals of classical optics:

- **Light propagation:** the idea that light travels from point A to point B in a straight line. This might be obvious to an adult, but a child just cannot see the point since there is no way to see it actually move.
- **Basic properties:** reflection and refraction of light, which is easy to introduce from the perspective of a beam of particles.
- **Detection and vision:** light is not emitted by our eyes, but rather reflected from objects in the path of a light source.

After this foundation has been established, advanced concepts can be introduced during preparation for university:

- **Wave model of light:** diffraction/interference and colour as wave-related properties of light.
- **Polarisation:** the angle of rotation of the electromagnetic wave and how it can be modified or constrained.
- **Quantum theory of light:** the basic notion that photons are an energy package that can be absorbed or emitted during energy transformations.

NANOTECHNOLOGY

Since nanotechnology lies somewhere between physics, chemistry and technology, its study could build bridges among the various STEM disciplines.

With the kind participation of Jordi Diaz (PhD in chemistry and material sciences; founder, Nanoeduca and Nanoinventum school activities; researcher, Universitat de Barcelona).

Underlying principle

Nanotechnology refers to any technological activity conducted at scales around 1 to 100 nanometers (1 m = 1,000,000,000 nm). This is the scale of atoms themselves, as the diameter of helium is about 0.1 nm.

Thus, nanotechnology applications provide extreme miniaturisation, using and rearranging individual atoms at will. Engineers are finding impressive new properties of materials at the nanoscale, such as enhanced strength, reduced weight and colour variations related to size. Similarly, many properties of known materials, such as conductivity or magnetism, show unexpected behaviours when broken down to their fundamental molecules.

To perform these processes, specialised tools have been developed, such as high resolution transmission electron microscopes (TEM) or scanning tunnelling microscopes (STM), powerful devices to actually see the atoms. For their part, atomic force microscopes (AFM) are capable not only to see but to actually move atoms around.

Nowadays, the applications developed at the nanoscale are widely used across disciplines, such as chemistry, biology, medicine, material science and engineering.

Historical background of nanotechnology

Practical effects of the nanoscale have been observed – if not understood – throughout history. The colour of many pigments relate to the nanoparticles that compose them. The strength and flexibility of Damascus steel blades are thought to be related to the formation of carbon nanotubes during forging. However, these observations remained largely unexplained for centuries.

It was Richard Feynman, in his inspiring lecture at Caltech in 1959, 'There is plenty of room at the bottom', who first raised the possibility that experiments could take place at the nanoscale and that atoms could be rearranged at will. This conference is regarded as the origin of today's nanotechnology, a term coined in 1974 by Norio Taniguchi.

Despite the lack of technology to really develop applications at the nanoscale at the time, Prof Feynman dismissed any theoretical limitations and predicted the development of some of the applications we see today.

The development of nanotechnology has been very dependent on the ability to see and manipulate things at a tiny scale. Thus, the milestones for its implementation correlate with the invention of the STM and ATM in the early 1980s.

This new technology, capable of rearranging individual atoms, was put to work for the first time in 1989, when IBM, the developer of the STM, used this device in a stunning demonstration, signing their company initials on a nickel surface with 35 xenon atoms.

The potential uses of atomic rearrangement, like nano-engineering and nano-robotics, have been discussed at length. However, few applications exist in this still-nascent field.

Most of the current advances in nanotechnology have to do with nano-coating surfaces with metal ions, such as silver or gold, to enhance the properties of existing materials, or designing new molecules with self-assembly capabilities to build structures from the bottom up, similarly to biological structures.

Despite the promise of huge benefits, recent concerns have arisen around the use of nanotechnology. Heavy metals, such as silver or gold, are known to be carcinogenic when ingested or inhaled. Likewise, some evidence suggests that carbon nanotubes might be as harmful as asbestos to our lungs.

Practical applications in everyday life

Current nanotechnology applications are mostly being used in mass production and industry, such as in the miniaturisation of electronic components or catalysts to capture harmful molecules and reduce pollution. The average citizen is not familiar with these applications, so knowledge of the nano world may seem a bit irrelevant to everyday life.

However, some insight on what happens at these tiny scales might open minds to new realities, new paradigms and lateral thinking. Citizens fully aware of the complex nature of our world might be more creative and critical.

Educational connection

Since nanotechnology lies somewhere between physics, chemistry and technology, its study could build bridges among the various STEM disciplines. For example, when the approach is practical, children can experiment on magnetism by using ferrofluids (and see the magnetic field in 3D) or consider the daily applications of superhydrophobic materials in the classroom.

In this regard, some efforts have been made to deliver nanotechnology activities to schools. The NanoEduca toolkit for secondary school (available internationally upon request) is a good example of these efforts, providing all the necessary materials and instructions, as well as a full educational plan to integrate activities in the classroom.

The experts contacted agree that both students and teachers are very receptive to activities focusing on the nano world, giving positive feedback on related activities. For teachers, the chance to approach classical concepts from another perspective proves highly engaging. Many teachers feel disconnected from the advances of contemporary science and technology, and working on the basics of an emerging field like nanotechnology boosts their motivation.

Nanotechnology applications also go far beyond the STEM paradigm, sometimes touching philosophy, social sciences and, ultimately, ethics. Consider, for instance, the claims that some nanoparticles might be harmful for us or for the environment. Can this issue be sorted out? How? Recycling of nanoparticles has proven to be quite difficult. Are the benefits worth the risks?

Other issues around nanotechnology that can be considered at the classroom level are those concerning the rationalisation of its use. Is it really necessary to use nanocomponents everywhere? Could this increase technological inequalities in the world?

Practical examples

- **Protection and conservation:** nanomaterials have been developed to help in the conservation of ancient works of art, such as paintings. Not only can these materials merge more naturally with the original objects, they can prevent future deterioration better than traditional methods.

- **Characterisation of materials:** the imaging techniques developed to study nanomaterials have applications in other fields, such as the identification of materials found at a crime scene or attributing a work of art to a particular artist.

- **New pigments:** some nanoparticles change colour depending on their size. This has led to the development of nanodyes, with many applications. Quantum dots, for instance, are used in molecular biology to tag proteins and other molecules into the cells and study their location.

- **Nanocircuits:** still under development, the ability to miniaturise circuits would allow their integration with any material, such as clothes. Once the technology is ready, a new era of wearable devices is expected.

- **Nanorobotics:** molecular machines that are fully programmable and controllable are envisioned, with enormous potential applications, such as medical robots operating inside our body.

References

Nanoeduca. Official website. [online] Available at: http://nanoeduca.cat/es
United States National Nanotechnology Initiative (2014). Nanotechnology timeline. [online]
Available at: https://www.nano.gov/timeline

Phys.org (2014). Nanomaterials to preserve ancient works of art. [online]
Available at: https://phys.org/news/2014-11-nanomaterials-ancient-art.html

ANNEX 1

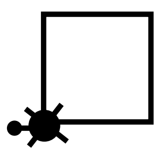
Differences between programming language based on syntax and languages based on blocks

Use **Logo** to draw a square measuring 50 pixels per side using a repetition loop.
The language is simpler, and there is little syntax.

to square

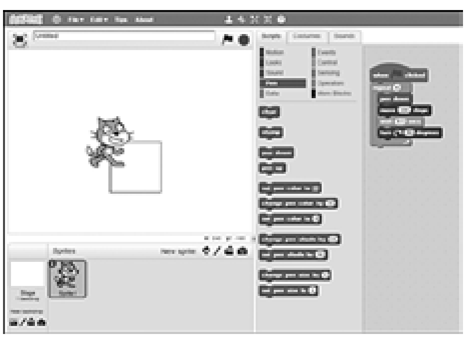
repeat 4 (forward 50 right 90)

end



forward 50 4x right 90

Use **Scratch** to draw a square measuring 100 pixels per side using a repetition loop. As shown, there is no code with syntax and thus there are no possible coding errors, only logical programming errors.



Use **JavaScript** (in combination with HTML5) to draw a square measuring 100 pixels per side. In this case no loop is used since the rectangle is directly defined. As shown, the language is much more complex, with a non-intuitive syntax and integrated functions (like *document* or *var*).

www.steamedu.eu

STEAM IMPLEMENTATION GUIDELINES

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sySTEAM

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CONTENTS

INTRODUCTION

The so-called STEAM disciplines (science, technology, engineering, art and mathematics) offer a unique opportunity for involving pupils in processes analogous to those in science: inquiry, experimentation, modelling, argumentation...

Participation in all these research practices helps pupils to understand how scientific knowledge is generated, making a holistic approach necessary for effective science and technology education.

This guide presents a set of technologies that are applicable to this learning context. The description of each technology includes implementation considerations, directions for their use in the classroom and examples of best practices that can inspire educators to apply the technologies in their own context.

This guide is the continuation of the report 'State of the Art of Stem Technologies'. The two reports, developed within the framework of the sySTEAM project (financed by Erasmus+ Programme of the European Commission) are complementary and worth consulting jointly


VOID PAINT();
}
PUBLIC INTERFACE
PUBLIC IBUTTON
}
PUBLIC CLASS WINFACTORY
@OVERRIDE
PUBLIC IBUTTON
RETURN NEW WINBUTTON
}
}
PUBLIC CLASS OSXFACTORY
@OVERRIDE
PUBLIC IBUTTON
RETURN NEW BUTTON
}
}
PUBLIC CLASS WINBUTTON
@OVERRIDE
PUBLIC VOID PAINT() {
SYSTEM.OUT.PRINTLN
}
}
PUBLIC CLASS OSXBUTTON
@OVERRIDE
PUBLIC VOID PAINT() {
SYSTEM.OUT.PRINTLN
}
}
PUBLIC CLASS MAIN {
PUBLIC STATIC VOID
IGUIFACTORY FACTORY
FINAL STRING
IF (APPEARANCE.EQUALS
FACTORY = NEW
} ELSE IF(APPEARANCE
FACTORY = NEW
} ELSE {
THROW NEW EXCEPTION
}
FINAL IBUTTON BUTTON
BUTTON.PAINT();
}
/**
* THIS IS JUST FOR THE
* WITH ABSTRACT FACTORY
* @RETURN
*/
PUBLIC STATIC STRING
FINAL STRING[] APPEAR
APPEARANCEARRAY[
APPEARANCEARRAY[1]
APPEARANCEARRAY[
FINAL JAVA.UTIL.RANDOM
FINAL INT RANDOMNU
RETURN APPEARANCE

General directions: using STEAM projects in the classroom

These guidelines present diverse technologies applicable in the classroom and describe their peculiarities. Although each is unique, there are common features. This introduction presents basic teaching recommendations to successfully deal with teaching STEAM in the classroom; these are also more widely applicable to any technology.

Teaching recommendations:

- **Adapt the classroom**. Pupils will need an appropriate space to work on the experiments, share ideas in teams, write and/or debate. The necessary material should also be provided according to the research design. In many cases, these materials can be low cost or available in the school labs, though there is the possibility of using simulators or virtual labs to carry out more sophisticated experiments.

- **Formulate proper questions**. Teachers should make sure that the teaching questions (whether these are formulated by the students or the teachers themselves) encourage students to deepen their reasoning. Questions that can be answered using simple definitions should be avoided. Furthermore, it is necessary to cultivate a classroom atmosphere where everybody can state their own opinions and answer questions without fear of being wrong.

- **Gauge pupils' pre-existing knowledge**. Pupils may already have some prior knowledge about certain phenomena, but this could be wrong or incomplete. The teachers' task will be to assess, complete and rebuild students' knowledge so that they are scientifically more accurate. Thus, it is a good idea to start each new class project with a debate about what students think about the issue they are going to research. Asking them to draw models or write explanations about how they think a certain phenomenon occurs is also recommended.

- **Organise group debates**. In this way, the students can share their ideas, see different points of view and learn from other classmates. These debates should not be carried out in a spontaneous way, but rather apply learning from previous training in debate culture. Respecting speaking times, thinking for a few seconds before responding, considering how to best express a point, or drawing conclusions from debates are all skills that pupils must work on in advance. Likewise, teachers should serve as the facilitator or moderator of the debate, but they should also allow pupils some autonomy to discuss amongst themselves.

- **Elaborate final products**. It is necessary to create different materials that allow the pupils to document their research process and review what they have learnt and how. Teachers can also consult these materials to assess the pupils' learning and, if necessary, to correct their understanding. Products could be lab notepads, experiment protocols, oral presentations and/or posters. Teachers might consider providing their classes with examples of different products as models. When reviewing the products, the teachers should be careful not to focus excessively on misspelling or poor syntax, but rather to guide students in improving their reasoning through constructive commentary.

Inquiry-based teaching

To introduce STEAM concepts in the classroom, inquiry-based science education (IBSE) is recommended as a teaching method that pivots on helping students truly understand what they are studying. IBSE avoids the superficial learning that memorising information and concepts implies.

Research on science education shows how curious students are from an early age about the world that surrounds them, highlighting their ability to articulate explanations about phenomena they observe in their daily lives. IBSE builds on this curiosity, helping to mould pupils' spontaneous conceptions into more scientifically accurate explanations through well-structured activities.

IBSE also allows students to work like scientists, avoiding an understanding of science lessons as a way to merely consume science products in favour of learning how to do science. In the same way that a person learns to cook by cooking or learns social skills when mingling with people, science is learned by doing science. The idea is that pupils should not be limited to repeating pre-formulated outlines; they should explore, research, draw conclusions and ultimately communicate what they have learnt.

To accomplish these objectives, teachers should make an effort to understand pupils' context and interests, designing activities and experiences that correspond to their level of knowledge, motivate them, and make them think about the phenomena surrounding them.

Bearing in mind that IBSE can be undertaken differently depending on the available tools, students' skills and teacher's knowledge, the following is a series of general considerations and teaching recommendations.

Basic considerations about IBSE:

- **Direct experience is important**. Pupils should be allowed to directly experience the phenomenon they are studying. Learning research tells us that outside of school, pupils learn and build concepts from direct experience with what surrounds them, so the same should happen in the classroom: different experiments should facilitate pupils' critical examination of their prior ideas and their formulation of new questions.

- **Question as a starting point**. Pupils must understand that their starting point in research should be a question. One way to motivate and engage them in their research is to give them the opportunity to raise that question themselves so that it becomes more meaningful for them.

- **Need for learning different skills**. To perform research, pupils must be capable of observing phenomena, asking questions, making predictions, designing experiments, analysing information and formulating statements based on evidence. The teachers' task will be to guide them during the whole process.

- **Beyond simple experimentation**. The science classroom should not be about undertaking hands-on experiments but about asking pupils to reflect on and discuss what is being produced. Debates about the experiment can be organised to stimulate ideas that can be written and refined.

- **Use of secondary information resources**. In IBSE it is necessary to consult other information resources, beyond direct experimentation. Students can consult books, the Internet or even experts to fill in the information needed for their experiment.

- **Science is a collaborative activity**. Pupils should work in small groups to share ideas, debate and think, just as professional scientists do. Teachers must create balanced and cooperative groups to better favour a work atmosphere that is conducive to each student making contributions according to their capacities.

PROGRAMMING

Programming cannot be an exclusive domain of technology or engineering ... Educational centres should be organised so that pupils can learn programming in all disciplines.

Objectives

Computing practice has recently earned its place in the academic curricula and is included in educational standards like K12 Next Generation Science Education Standards. This is because programming, more than an aim in and of itself to learn certain computing languages, is a means for pupils to participate in processes analogous to scientific activity.

Programming in the classroom helps pupils to:

- be capable of building models of the phenomena surrounding them, through the abstraction of concepts;
- acquire problem-solving skills, since programming is nearly immediately responsive to inaccuracies;
- develop creativity and imagination; and
- learn different programming languages, for instance, Scratch or Processing.

Tips for using programming in the classroom

Whether programming is used in the classroom as a means or as an objective, experts' advice is often the same. The following tips are especially relevant:

- **Separate digital language from the science to be learnt**. Students have to acquire some basic programming skills before applying them to new learning material. Teachers can start by asking pupils to programme games (like video games) or animations where different characters interact, which will motivate them while simultaneously familiarising them with the functioning of the software.

- **Be incremental**. If students are supposed to programme a certain model of any natural phenomenon, then they should start with simple processes, for instance, the warming of a glass of water in the sunlight. Henceforth, other more complex processes can be modelled, like the distribution of power from a Van der Graaf generator. Likewise, if an activity aims to teach students how different programming languages function, they should start with simple tasks that do not imply many orders, so that the pupils can get comfortable with them step by step.

- **Use cross-cutting tools**. Programming cannot be an exclusive domain of technology or engineering. It must be cross-disciplinary, touching all subjects. Educational centres should be organised so that pupils can learn programming in any discipline.

- **Use the tool to promote diverse approaches**. Programming allows each pupil to work independently, meaning that everybody can learn and work at their own pace. That's why it is important to establish clear objectives when planning activities, bearing in mind that pupils will always have to start by outlining their model on paper. For instance, when programming a game, it is vital that rules are clear from the start; for an animation, programmers must sketch an outline; and when explaining a natural phenomenon, it is necessary to know what factors play a role.

Considerations before implementation

First, teachers have to know and master the programming software to be used. It is advisable to try out different ones to see what functionalities each has. The simplest ones that secondary pupils can use are Scratch (it is not necessary to know programming language), Processing (with a syntax based on Java but accessible to novices) or an adaptation of Scratch called Arduino (for programming in robotics). All of them are open-source codes and affordable to any school.

Secondly, teachers should monitor pupils' frustration to find the right balance between guided and independent work, as the activities will have both phases, and teachers should aim to intervene only when their students need it. At first, all pupils can work on the same activity and then break off according to their objectives. In this sense, programming should not become an obstacle for pupils to model a particular phenomenon.

Finally, the STEAM paradigm may initially appeal only to a certain profile of pupil (boys with a specific background or interest in science), so the challenge for the teacher will be to engage other pupils as well. One way to do this is to link programming activities to different fields and social issues.

Resources

Computing at School: website promoting programming in the classrooms with a virtual community to give resources and tutorials through fora (http://www.computingatschool.org.uk).

Processing: software processing website with tutorials, guidelines, and examples for their use (https://processing.org)
Scratch for Educators: on the page for teachers, there are tutorials, guidelines and opportunities to work online with students (https://scratch.mit.edu/educators).

Brennan, K., Resnick, M. (2012). New Frameworks for Studying and Assessing the Development of Computational Thinking. In: Annual Meeting of the American Educational Research Association Vancouver: American Educational Research Association, pp. 1–25.

Wagh, A., Cook-Whitt, K., Wilensky, U. (2017), Bridging Inquiry-based Science and Constructionism: Exploring the Alignment Between Students Tinkering with Code of Computational Models and Goals of Inquiry. Journal of Research in Science Teaching, 54, pp. 615–641.

Practical examples

Scratch Tutorials: video tutorials with different examples of possibilities for making games and animations (https://scratch.mit.edu/help/videos).

BBC Schools Computing: BBC webpage giving resources to explain certain programming concepts to Secondary pupils (https://www.bbc.com/education/subjects/zvc9q6f).

ROBOTICS

Experts recommend designing and performing meaningful activities that transmit to pupils that modern engineering is interdisciplinary in nature and aims to solve social problems and needs.

Objectives

Because robotics requires developing and materialising an idea, it is a cross-cutting discipline that draws from different spheres: engineering, mathematics, physics, electronics, programming and design, even the software SketchUp for 3D printing. Thus, it is a very good option to work on different educational aspects:

- To turn abstract concepts into reality and make them more understandable for pupils.
- To favour students' independence and capacity for problem-solving, since they create their own ideas.
- To awaken students' vocations for science and technology.
- To allow pupils to work in groups and to improve the classroom cohesion.

Moreover, work in robotics is based on an inherently holistic perspective, as the purpose of the activity is to introduce a device that satisfies a certain need or improves an existing tool. Thus, students must consciously connect with their surroundings.

Tips for using robotics in the classroom

Using robotics in the classroom should be rooted in the need for holistic and inquiry-based work, taking the following aspects into account:

- **Make activities progressively difficult**. Although the objective of robotics is to build an object that all students have to conceive in order to solve a real-life problem, they will need a foundation of skills, especially in the field of programming. Experts recommend carrying out small previous exercises, with very simple guidelines, so that pupils perceive the correlation between programming and robotics and acquire the knowledge they will need to build their device.

- **Organise working groups**. Successful progress in robotics projects largely depends on teachers' ability to organise their pupils in balanced groups with different abilities and skills. If this step is achieved, students will find it easier to perform a single task, such as coordinating the group's work, explaining the project to classmates, or applying maths skills or spatial vision. Groups can also integrate pupils' diverse strengths. The maximum recommended number of pupils is 4.

- **Require final products**. Besides the robot itself, project-based activities should be accompanied by a project report, detailing the technological process; an oral presentation in front of the rest of the group (as in a science fair or a sales pitch for a prototype); and a video showing the functioning of the robotic device (this is ideal in case something fails and does not work properly during the live presentation).

- **Assess all facets of the project**. In addition to grading the final product of a robotics project (whether or not the robot works), other items should also be assessed, including group coordination and individual participation. Likewise, pupils should have the opportunity to assess the other projects, even voting for the best one.

- **Make activities meaningful**. As a complementary issue, experts recommend designing and performing meaningful activities that transmit to pupils that modern engineering is interdisciplinary in nature and aims to solve social problems and needs. For instance, educators can organise visits to universities, engineering schools, companies, start-ups, and even congresses and technological fairs.

Considerations before implementation

Even though robotics activities may initially seem complex, experts urge teachers not to let lack of confidence stop them from experimenting with these projects in the classroom. Continuous professional training could help to familiarise teachers with the material. Moreover, teachers might be motivated by the fact that pupils already have mental strategies that make working in this way easier: robotics is very proactive and attractive, and it facilitates joint teacher-pupil learning.

No big technical requirements are needed for implementing robotics activities, facilitating their use in the classroom. The indispensable needs are computers (preferably laptops for improving the flexibility of the space), robotic plates connected to them, and materials that pupils will use to develop their projects. These materials could either be loaned to students by the school, or pupils could research and supply their own material needs.

Pupils must have minimum programming skills in the software needed. These skills could be developed through prerequisite coursework or in parallel to other disciplines. For instance, a working knowledge of Arduino is useful, since its simplicity makes it one of the most recommended tools for initial class work in robotics.

Resources

Arduino: website where educational applications of Arduino software can be found
(https://www.arduino.cc/en/Main/Education).

Lego League: robots competition that motivates pupils to find solutions to current world challenge like recycling, food safety or energy sources (http://www.firstlegoleague.org).

RiE 2017: website of the 8th International Congress on robotics in education (http://rie2017.info).

Sterling, L. (2015) Five Reasons to Teach Robotics in Schools, The Conversation, [online] Available at:
http://theconversation.com/five-reasons-to-teach-robotics-in-schools-49357 [Accessed May 2018].

Practical examples

Hackster: community dedicated to learning Arduino software, with examples of its use (https://www.hackster.io/arduino/projects).

RoboESL: European project that uses robotics to prevent school dropout (http://roboesl.eu).

Blog S4A: practical examples and in different levels of robotics projects using Scratch for Arduino (http://blog.s4a.cat).

Botball: project whose goal is to encourage the application of robotics in the classroom by participating in a robot competition (http://www.botball.org).

REMOTE VIRTUAL LABS

A wide range of possible classroom applications fall under the umbrella of 'virtual and remote labs', from small simulations to the collection of real data from research centres like the European Organisation for Nuclear Research, CERN.

Objectives

Virtual labs, simulators and remote labs have different purposes in the classroom:

- To facilitate experiments and practicals that cannot normally be carried out in the educational centres' labs owing to lack of equipment.
- To carry out experiments without any risks, thus reducing pupils' aversion to making mistakes.
- To help illustrate phenomena or structures that are difficult to represent with traditional methods like blackboards.

Offline labs cannot be completely replaced by online ones; rather, the two tools are complementary. Besides, students may resent the overuse of electronic devices (PCs, laptops, tablets).

Virtual and remote labs can be used in different scientific and technical disciplines: physics, chemistry, biology, technology (engineering) and mathematics, to varying degrees. For example, there are more possibilities in physics than in mathematics. These tools can be also introduced at any moment of the didactic sequence.

Thus, this kind of technology is perfectly aligned with STEAM methodology, enabling pupils to participate in the scientific process, encouraging them by making science lessons more enjoyable and entertaining, and allowing them to experience greater diversity in classroom activities.

Tips for using virtual and remote labs in the classroom

A wide range of possible classroom applications fall under the umbrella of 'virtual and remote labs', from small simulations to the collection of real data from research centres like the European Organisation for Nuclear Research, CERN. So, there is an array of heterogeneous tools, and each proposal can require specific adaptations. Educators should keep the following tips in mind:

- **Plan simple activities with clear objectives**. Pupils will achieve the best results from using these technologies if activities are straightforward and the goals are clear. This means that although pupils can work independently, guidelines and instructions must be easy to understand so that students' curiosity can be freely explored, and so they can learn the need for systematising research.

- **Monitor activities**. Teachers play a guidance role during the activities even if experts recommend not controlling the entire process. Teachers should pause the activity from time to time to share issues and discuss pupils' progress. Otherwise pupils may simply play with the simulations without using them properly.

- **Generate results**. It is necessary to create a final product, which could be a report on the practical or a question worksheet on the part of the scientific process that the class is working on. For instance, pupils might answer a few initial questions, make a hypothesis or write the conclusions of the experiment.

- **Use the technology properly**. Virtual and remote labs should be used only when they are really necessary, for instance, to simulate an experiment that cannot be carried out at the school due to lack of appropriate resources. Simulations should complement real experiments, not replace them.

Considerations before implementation

A good Internet connection is indispensable, as are computers or tablets for the pupils (at least one per pair). This facilitates the use of this technology in any class of the school.

Teachers must have enough time for correctly planning and designing the activities, avoiding improvisation. To use GoLab virtual labs, some preliminary training with the Graasp tool is necessary.

GoLab laboratories have an excellent teaching environment, providing pre-programmed and easy-to-apply lesson units, although sometimes it is preferable to adapt them to the pupils' characteristics and their educational context.

Resources

University of Colorado simulators (https://phet.colorado.edu).

Go-Lab Project: well-developed teaching environment with labs from around the world, heterogeneous functions, and possibilities for sharing and adapting teacher-designed activities (https://www.golabz.eu).

Scientix: science education community in Europe: resources and examples of virtual and remote labs (http://blog.scientix.eu/2015/08/virtual-laboratories-in-teaching-and-learning-science).

ChemCollective: virtual labs for teaching chemistry (http://chemcollective.org/home).

Vozniuk, A. (2017). Enhancing social media platforms for educational and humanitarian knowledge sharing: analytics, privacy, discovery, and delivery aspects. [pdf] Lausanne (Switzerland): École Polytechnique Fédérale de Lausanne. Available at: http://www.go-lab-project.eu/sites/default/files/files/publications/file/EPFL_TH7495.pdf [Accessed May 2018].

Practical examples

Faulkes Telescope Project: a network of robotic telescopes which allows visualisation of real astronomical images in the classroom. It also provides examples of related activities (http://www.faulkes-telescope.com).

Galaxy Crash: simulator of galaxy collisions, allowing the comparison of predictions made by students (https://www.golabz.eu/lab/galaxy-crash).

Vcise: Drosophila Melanogaster Genetics Experiment, a virtual lab applying genetic principles to vinegar flies and observing the results of modification of hereditary patterns (https://www.golabz.eu/lab/vcise-Drosophila-melanogaster-genetics-experiment).

EDUCATIONAL VIDEO GAMES

... beyond the objective of motivating and involving students during lessons, video games should be used for the pupils to imitate the context in which scientists and engineers work.

Objectives

Many types of video games can be used in science, technology and mathematics classrooms, including arcade, sandbox, quiz, strategy, simulation and target practice games ... Their educational value resides in the focus given to them. Experts distinguish between video games that aim to improve classroom dynamics and those focusing on doing better science.

In the STEAM sphere, pupils can use video games to learn how to do science, that is, to practice three aspects of scientific practice: modelling, inquiry and argumentation.

Thus, beyond the objective of motivating and involving students during lessons, pupils should use video games to imitate the context in which scientists and engineers work.

Without discounting the value of other kinds of video games, the ones that are most closely aligned with the premise of emerging trends in science education, captured in educational standards like K12 Next Generation Science Standards (NRC, 2012), are games that pose an intellectual challenge. Pupils must solve the problems by building a model or an explanation, often acquiring new skills along the way. The reward systems built into the games simulate the social context of scientific practice.

Tips for using educational videogames in the classroom

- **Consider at what point in the didactic sequence to introduce the video game**. The great variety of existing video games makes it possible for teachers to use different types for working different aspects of the scientific context. So, the teacher's task is to correctly sequence the use of the video game to make it a meaningful part of the learning process, whether it is used in the moment of inquiry, the framing, or in the application of knowledge.

- **Ensure a simple initiation**. All pupils will have to be able to master at least some of the video game, and henceforth the teacher will have to facilitate progress through more complex stages. There are video games allowing gamers to advance through different levels as they acquire the skills for solving more complex models or finding more elaborate answers and explanations.

- **Combine online and offline activities**. Evidence in didactics research shows that students learn less when using only online technologies or digital tools than when they combine on- and offline activities, like paper and pencil activities or hands-on practical experiments.

Considerations before implementation

Teachers should consider aspects related to the video games themselves as well as the aims of the activities. Experts highlight the following:

- **Use of rewards**. Although the objective of the video game is competitive, rewards cannot be linked to a traditional teaching paradigm. Strategies recreating the conditions of people doing research could be developed. For instance, as the game advances, participants could win points towards obtaining materials for use in the school lab practicals.

- **Elaborate solutions**. Players should not be able to win the video game using a simple Internet search, but by giving complex answers that lead to other questions.

- **Not focusing on purism**. Pupils should be able to advance in the video game without having to use specific language or knowledge. It is more important that students be able to structure and relate concepts than to know a certain vocabulary.

- **Importance of pupils' previous background**. Students frequently think of possible solutions, which are often incorrect or ambiguous, and the video game should help to reformulate these concepts.

There are a number of digital platforms gathering different video games, many of which can be played online, thus facilitating their use in any space in the school centre where students have access to an Internet connection and a device.

Resources

Brain Pop: website dedicated to the use of digital tools in education, presenting different resources like video games and simulations classified by themes. All are accompanied by teaching suggestions and complementary material (https://www.brainpop.com).

Physics Games: set of games based on physics and with different degrees of complexity (http://www.physicsgames.net/)
Dragon Box: portal with different computer and mobile applications of online games that can be downloaded, for a fee (https://dragonbox.com).

Funbrain: website offering hundreds of educational video games, plus books, comics, and videos for working on maths and solving problems, among other activities (https://www.funbrain.com).

Practical examples

Bridge Builder (Physics Games): video game where players must act as if they were engineers designing and building a bridge for a truck to arrive at its destination (http://www.physicsgames.net/game/Bridge_Builder.html).

Guts and Bolts: video game where players work through several screens, making an anatomical model related to circulatory, respiratory and digestive systems (https://www.brainpop.com/games/gutsandbolts).

Geniverse lab: game allowing the pupils to plunge into the study of genetics and heredity by feeding and studying virtual dragons (https://learn.concord.org/geniverse).

LOW-COST EXPERIMENTATION

Low-cost experiments can be done from any subject perspective and can be applied at any moment of the didactic sequence.

Objectives

There are two main objectives for using this kind of technology in the classroom: first, to do science (inquiry and experimentation), with the added value that experiments are done easily, occupy little space, are low cost and can be done at home. The second objective is to involve pupils and encourage them to practice science.

However, each experiment should also have its own specific objectives, which will shape the derived activities. This design will link low-cost experimentation to a greater or lesser extent with different scientific and technical disciplines.

Low-cost experiments can be done from any subject perspective and can be applied at any moment of the didactic sequence. At the beginning of a lesson, these experiments can be used to elicit hypotheses about a certain phenomenon or to stimulate their curiosity. Other times, the experiments can fall in the middle of the sequence to explore what is happening or to predict what will happen. At the end of a lesson, experiments can be done after explaining a certain part of the curriculum by asking the students to interpret the results of a low-cost experiment with the acquired knowledge.

Doing a low-cost experiment in the classroom does not, in and of itself, teach students to behave like scientists. It is the teacher's job to help students learn these skills by properly designing activities related to the experiment. Rather than providing the class with a pre-prepared, closed protocol to be reproduced, teachers should encourage pupils to formulate questions about how and why something works.

Tips for using low-cost experimentation in the classroom

- **Get motivated**. Teachers must be motivated to conduct these experiments without fear of malfunctions. This can be promoted through previous training to learn new experiments. Online resources on low-cost experimentation can also be consulted.

- **Ration their use**. Sometimes, students continually ask to do experiments, but teachers should only use them to achieve pre-defined learning objectives.

- **Design clear activities**. For pupils to become familiar with practicing the scientific method, activities should be designed in a very clear way to work different concepts, like hypothesis, conclusions, validation, etc.

- **Seek flexible spaces**. Although there are no big technical requirements to conduct these experiments, classrooms should have the flexibility to adapt the space to the needs of the experiment (tables and chairs not fixed on the floor). A few experiments can even be done outdoors.

Considerations for implementation

Low-cost experiments are offline and can be applied to any level of secondary education, although each involves a different level of interpretation, depending on the difficulty of the contents worked on during each stage.

- **Do a trial run**. Experts recommend teachers test the experiment before carrying it out in the classroom with the pupils.

- **Use them frequently**. This kind of experiment should be done regularly so that pupils develop the necessary habits and understand the norms that will eventually allow them to work independently. Students should work in small groups of 2 to 4 people.

- **Design a suitable sequence for the activity**. Low-cost experiments should not simply replicate protocols previously facilitated by the teachers; instead they have to allow students to reflect on how to carry out a certain demonstration, thus facilitating meaningful learning.

- **Produce results**. It is important that students produce a digital or hard-copy record, where they can think about the experiment and avoid understanding it as a simple game. Any number of final products can be produced: from an assignment with closed questions to a lab notebook where all the experimental steps are written.

- **Perform a final assessment**. The final assessment should serve two purposes: first, it should evaluate the pupil's interpretation and academic progress, and second, it should examine whether the experiment works. Experts recommend asking the pupils to assess the experiments conducted during the academic course. In this way, teachers can obtain very valuable feedback, letting them know whether certain aspects or their approach to the experiment should be rectified.

Resources

Poppe, N., Markic, S, Eilks, I. Low cost experimental techniques for science education (2010). [pdf] TEMPUS, European Commission. Available at: http://www.idn.uni-bremen.de/chemiedidaktik/salis_zusatz/material_pdf/lab_guide_low_cost_experiments_englisch.pdf [Accessed May 2018].

Practical examples

Microecol: collection of information and examples of low-cost chemistry (https://www.microchem.de).

Science Kids from New Zealand: videos with experiments of Science and technology for youngsters (http://www.sciencekids.co.nz/videos/experiments.html).

3D PRINTING

Experts recommend having a 3D printer in the classroom to enable collaborative work with different departments, employing a transversal vision of the activities and projects.

Objectives

The potential to use 3D printing as a tool in STEAM education is enormous, since this technology enables linkages between different disciplines, including engineering, technology, mathematics, artistic expression, biology or chemistry. However, teachers must understand that the main objective must be for the pupils to design their own object to be printed.

In this way the pupils:

- answer a certain need, including one proposed by the teacher (for example, to create a decorative object for the room, compete in a contest for designing objects related to the school, or obtain pieces for building a robot or another electronic device);

- test the viability of their designs, because often the pupils tend to design objects that 3D printers cannot print. By trying it out, they will be learn how technical limitations affect engineering or research projects;

- learn to make models, as they will have to express their ideas and make drawings with the support of suitable software.

For all these reasons, the consulted experts agree that 3D printing is a good classroom resource for science and technology.

Tips for using 3D printing in the classroom

- **Familiarise students with the design software**. Pupils should start at the early stages of secondary school to familiarise themselves with the use of software for designing things to be printed, like Scratch. Curricular continuity should ensure that as pupils move forward in the courses, their needs be met with printable objects.

- **Play a guiding role**. Teachers will be in charge of proposing activities to encourage pupils while also favouring their independence, while at the same time analysing whether the presented designs are viable and fit the lesson objectives. Some margin for error must be allowed for pupils to realise their mistakes on the design once printed.

- **Diversify activities**. Experts suggest putting into practice different kinds of activities linked to the established objective. There can be activities like contests, where the winners are chosen by their classmates based on their design and get to print out the object to be given as a present to the school. Another possibility could be making printing part of a larger robotics project. The usefulness of 3D printing for working jointly with other disciplines, for instance mathematics when visualising or calculating geometrical figures, can be explored.

- **Use both individual and collective work**. Pupils should start working alone in the first stages, to get familiar with the software. Later, task-based activities and more complex work can be done in pairs, and for even larger projects, groups of 4 or 5 people are better so that pupils can share ideas and abilities.

Considerations for implementation

3D printers are delicate and expensive devices: pupils should not be responsible for their maintenance, even though it could be supervised by the teachers. The goal of activities with 3D printers is that pupils take part in the process preceding their use, rather than receptively learning the mechanics and functioning. However, teachers can ask for their pupils' collaboration to do the file transfer to the printer so that they participate in the whole process.

Even though the notions for using 3D printers can draw from subjects closer to engineering and technology, the teachers of other subjects could also make use of it for their own activities.

Finally, with regard to more technical aspects, teachers should follow several precautions, like using a suitable plastic for each kind of printer and avoiding blows or brusque movements that will cause an imbalance in printing.

Resources

Create Education: website from the United Kingdom offering resources for implementing 3D printing in the classroom, both in primary and secondary school (https://www.createeducation.com/resources-landing).

3D printers in schools: uses in the curriculum; a report by the British Government about a study introducing 3D printers in 21 schools (https://www.gov.uk/government/publications/3d-printers-in-schools-uses-in-the-curriculum).

Practical examples

Project on the creation of a molecule for a biology classroom
(https://ultimaker.com/en/resources/50531-ap-biology-capstone-project).

Fabrication of a chess game in 3D
(https://ultimaker.com/en/resources/50520-checkmake-3d-printed-chess-set).

Creation of a stamp and a ceramic box in 3D
(https://ultimaker.com/en/resources/50534-3d-printed-pattern-stamp-ceramic-box).

Creation of 3D silhouettes with Photoshop
(https://ultimaker.com/en/resources/50530-creating-a-3d-silhouette-using-photoshop).

OPTICS AND PHOTONICS

The complexity surrounding the phenomenon of light makes it imperative for pupils to experiment with its properties first-hand and to have the opportunity to build their own models.

Objectives

Even though light is the manifestation of energy that provides the most information about our surroundings, most of the population has erroneous ideas about its nature. This fact is not surprising, as light is a complex phenomenon that is difficult to understand, with physical parameters that greatly outstrip human capabilities of perception. According to experts, the concepts of light have even been taught incorrectly in schools.

Thus, the main objective of carrying out experiments in optics and photonics is to improve students' understanding of light and its properties. This means that pupils should receive comprehensive instruction about light as both a wavy and corpuscular phenomenon, which explains its interaction with matter both at micro and macroscopic level. Therefore, the first task should be to clarify previous concepts the pupils may have about reflection, refraction, absorption, dispersion, diffraction or photons, among others.

Pupils should learn how to explain daily phenomena, ascertaining what light model they to apply (geometric, wavy, quantic) according to the event they are analysing. In this way, many intuitive – and possibly wrong – ideas that pupils may have had can be corrected.

The complexity surrounding the phenomenon of light makes it imperative for pupils to experiment with its properties first-hand and to have the opportunity to build their own models.

Tips for using optics and photonics in the classroom

The curricular content on optics should be tailored to students' cognitive level at each educational stage. For instance, at the early stages of secondary school, educators can work on concepts linked to light as an energy source (emission, reflection, refraction, absorption and detection), whereas concepts regarding light as a wavy phenomenon, along with geometrical and quantum optics, can be introduced at the end of secondary education.

Experts have the following recommendations for teachers:

- **Conduct small research projects on the phenomenon to be studied**. According to the educational level, these can be as simple as examining the differences between pupils' glasses or analysing the shape of cars' side mirrors. More complex experiments could be based on virtual labs and simulators (for instance, to work on the types of light sources, ray diagrams, refraction and reflection laws, the mechanisms of vision and polarised light). These experiments must draw from the daily phenomena in students' lives so that they can better grasp the concepts at hand.

- **Be very careful with language**. Since pupils' previous ideas often differ from a scientific vision, their explanations can contain language errors hindering learning. In this sense, experts recommend not assuming that students understand certain concepts; even if these seem like basic, everyday concepts, students may not understand them, for instance the fact that light travels in a straight line.

- **Make diagrams and drawings**. This is a good way to help pupils model the properties of light, especially geometrical optics. Optics can often be represented by lines, for instance to show the trajectory of beams, mirrors or the angles of optical laws. This representation can help students remember and understand concepts better. Diagrams and drawings can also be of use for the teachers to see students' pre-exiting conceptions.

- **Work in groups**. It is advisable to organise small work groups so pupils can share ideas, debate and help themselves when carrying out their research projects.

Considerations before implementation

Since optics and photonics link physics to other disciplines like mathematics (STEAM) and allow pupils to work like scientists, experts agree that the teachers must have a strong will for promoting experimentation in these fields from primary school.

Teachers should start with very elemental practices. For instance, pupils can independently deduce the law of reflection by playing with mirrors to guide a light beam; just synthesising these key concepts would not be as effective in building students' understanding. In general, these practices do not require great technical investments, and a few can even be done with virtual simulators.

However, experiments alone are not enough to teach pupils science: they should be allowed to propose experiments, not just reproduce the teachers' given protocols or perform a list of activities.

Resources

Costa MFM (2008). Hands-on science. In: Costa MF, Dorrío B.V., Michaelides P., Divjak S., editors. Selected Papers on Hands-on Science. Lisbon: Associação Hands-on Science Network, pp. 1-13. ISBN 978-989-95336- 2-2.

Tekos, G., Solomonidou, C. (2009). Constructivist Learning and Teaching of Optics Concepts Using ICT Tools in Greek Primary School: A Pilot Study. Journal of Science Education and Technology, 8(5), pp. 415–428.

National Science Teachers Association: website of the NSTA where resources about different subjects classified by levels and themes can be found (http://www.nsta.org/elementaryschool).

Atmospheric Optics: website where explanations and diagrams about atmospheric optics can be found
(http://www.atoptics.co.uk).

Practical examples

Practical Physics: website of the Institute of Physics, with different physics experiments, including in optics and light (http://practicalphysics.org).

Optics 4 kids: a selection of different optics experiences to be done at school, classified by ages (https://www.optics4kids.org/classroom-activities).

Optics: light, color, and their uses. Educator guide. Published by NASA, this guide has different experiences around optics and light ordered according to the pupils' age (https://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Optics.Guide.html).

NANOTECHNOLOGY

> *[Nanotechnology] generates debate on risks and ethical aspects associated with scientific practice, thus stimulating pupils' critical spirit.*

Objectives

The existing evidence about applying nanotechnology in the classroom states that:

- it is a good model for STEAM since it favours breaking down barriers between different spheres of knowledge, forcing teams to work in a multidisciplinary way, with researchers having to improve and learn from other fields;
- it allows pupils to be in touch with recent scientific and technical discoveries, seeing their impact on everyday life;
- it generates debate on risks and ethical aspects associated with scientific practice, thus stimulating pupils' critical spirit;
- pupils are in contact with a more authentic way of doing and communicating science.

Tips for using nanotechnology in the classroom

The consulted experts agree on the following tips for implementing nanotechnology:

- **Accompany it with as many practical activities as possible**. Nowadays, some teachers' resource centres have kits with school materials for carrying out low-cost experiments (with dice, effervescent pills, etc.).
- **Use nanotechnology to explain common science**. For instance, when working on magnetism, teachers can make use of the ferrofluid properties; on optical properties, they can use gold without the expected colour; and on biology or chemistry, they can link their work to the biocide capacity of silver.
- **Start with daily problems or situations**. Ask the class about the state of the art in a particular subject, for example, treatment for a particular kind of cancer, and find how nanotechnology might help, thus promoting pupils' interaction with their environment.
- **Take advantage of Internet resources**, whether they are didactic videos or augmented reality, that helps pupils understand and visualise the world of nanotechnology.
- **Complete classroom activities with visits to research centres and laboratories**.

Considerations before implementation

- The use of nanotechnology as a classroom resource entails specific teacher training in this field. This training should be practical as well as technical, providing teachers with the knowledge they lack owing to the discipline's emerging nature. At the same time, teachers should obtain practical examples and use them in the classroom.

- It is also advisable to strengthen pupils' work in small groups of 4 to 6 people, who create a final product in the form of a video or scientific poster where they have applied their skills in digital tools, communication and synthesis.

- On a technical level, nanotechnology activities do not present great requirements beyond a school lab and computer devices.

Resources

Statnano: Nano Science, Industry and Technology Information: indicators and statistics about nanotechnology development on a global level (http://statnano.com).

National Nanotechnology Initiative: educational material and other initiatives related to nanotechnology from the US government (http://nano.gov).

Nanopinion: website with examples of activities and videos about nanotechnology and teacher training (http://nanopinion.archiv.zsi.at/en/education.html).

Practical examples

Nanozone: examples of activities about nanotechnology (http://www.nanozone.org/teachers.htm) (examples of activities about nanotechnology).

Nanoyou: different examples of experiments with nanotechnology (https://nanoyou.eu/en/virtual-lab.html).

Nanokomik: multidisciplinary and international project about collaborative creation for disseminating nanotechnology through comics (http://www.nanokomik.com/index.php/en).

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