STATE OF THE ART OF STEM TECHNOLOGIES WITH APPLICATIONS IN THE CLASSROOM

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INTRODUCTION

The main goal of the sySTEAM Project is to increase the use of STEAM education ensuring quality and smooth implementation of inquired-based, project-based, problem-based and trans-disciplinary learning.

This report about the State of the Art of existing and emerging technologies to be used in the classroom is the first step to achieve that goal.

The selection of technologies presented here involves a sufficiently wide range of possibilities so that each school can identify the applications that can best suit their needs. They are technologies with different degrees of maturity and development worldwide (therefore they have been classified as 'consolidated' or 'emergent') and that have been considered suitable for their ability to mobilize transversal STEM projects.

For each technology, diverse aspects have been analysed: Working principle, historical background, practical applications, educational connection and practical examples. The intention has been to give a general overview to assist the science teachers in preparing more creative, problem-solving and critical pupils for the future.

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

CONSOLIDATED 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 from the Technical University of Catalonia – UPC; MBA from ESADE Business School and Secondary School Teacher) and Joan Alemany (Graduate in Mathematics from the Technical University of Catalonia – UPC; cofunder of eSeeCode and Secondary High School Teacher).

Underlying principle

In Computer Science, we mean by *programming* the action of translating into a computer language a series of previously designed instructions (algorithms) for processing a dataset according to a intended purpose.

Any programming strategy requires a prior modelling of the problem to be resolved, from applying computer thinking. This requires an in-depth analysis of the problem and a top-down design process separating possible resolution in automated processes.

Programming a computer application is based on logic, knowledge of sequential processes and the correct use of the particular syntax of the programming language used. Therefore, you can write a programme without knowing deeply the hardware that will be used.

Historical background of Programming

As such, programming was developed during 20th century in Europe and, above all, in the United States, with applications for the large electronic calculation machines of the Second World War (such as ENIAC, the large computer). By the end of 20th century, they emerged with the rise of microelectronics and the first high-level programming languages.

BASIC, Fortran, Pascal provide a reasonable interface, between a pseudo-human language and the machine code. Today, the most commonly used programming languages —C++, JavaScript, Phython, PHP— include a large number of 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 the rigid syntax in the code, with very visual proposals, which are generally based on interactive blocks placing more emphasis on the logical structure of the programme and less on syntactic correction. Scratch, Swift Playgrounds and GPblocks are good examples of this. Although they are widely use as pedagogical models, they are true 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 we are increasingly interacting (and more intimately) with all types of technological elements, from more or less complex machines to sophisticated software, programming knowledge will provide us with the tools to effectively understand and use, for example, mobile devices, professional computing applications, social media or even smart appliances.

This last point is very important and the current trend to connect all types of devices is called to shape the so-called Internet of Things (IoT), which will pose great challenges for privacy and processing personal data. Accordingly, it will also allow to developing technologies based on the analysis of large datasets, or Big Data, probably by tools running artificial intelligence.

Therefore, 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 grounds of computer programming suited to young people is as old as the programming itself. One of the first systems adopted by schools was the Logo (designed in 1967) which, with various updatings, still keeps its iconic turtle as an educational tool. However, some experts admit that under-investment in hardware in schools, due to the crisis in the 90s in Europe, maintained programming skills primarily outside the basic academic curriculum. Not until a new century arrived that, taking advantage of economic growth in Europe in the period 2004-2008, computer-promotion programmes arise in schools. Programming returns to the early stages of education, and lower hardware costs, with good graphic performance, popularise Scratch as a standard visual programming language (developed in 20015 and partially inspired by Logo). This programming system, based on manipulating interactive blocks rather than writing lines of code, avoids the frustration at 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 are born (Swift, GPblocks, eSeeCode or Tynker) aimed at improving some features that have not yet been completely solved in Scratch.

At present, programming, as a part of computer skills and new technologies, is included in the academic curriculum at all stages of education in most EU Member States and is considered a key skill in the training of the future citizens. In particular, programming at the primary and secondary education use a series of transversal 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.
- Teamwork (in large projects).

Practical examples

Experts agree that there is no single way to learn programming skills and students develop them as needed the tools. Therefore, creation-based approaches are fundamental. The concept would be "Programming to learn" rather than "Learning to program".

CREATION OF SIMPLE GAMES

Programming a simple game, such as Domino or Solitaire, or else more complex as a platform game, face students with multiple challenges that must be addressed by applying programming strategies based on the problem analysis. These small games allow you not only to develop the programming part, but also artistic aspects (graphic design) and literary features (writing instructions for the player).

MAINTENANCE OF A WEB SITE

Many teachers in the STEM areas encourage students to maintain a joint class web site, including various information about the academic course. This can be used to work with the 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, aspects such as design, content writing and communication will also be tackled.

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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 from the Technical University of Catalonia – UPC; MBA from ESADE Business School and Secondary School Teacher), Joan Alemany (Graduate in Mathematics from the Technical University of Catalonia – UPC; cofunder of eSeeCode and Secondary High School Teacher) and Frank Sabaté (specialist STEM teacher).

Underlying principle

Robotics is a transversal discipline that deals with the study, design, construction and application of robots. Conceptually, it is born with the same idea of robot, although the adoption of *robot* and *robotics* terms have a peculiar history.

Due to its natural multidisciplinarity, robotics is based 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 will be 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 a unified definition about what a robot is. However, experts agree that a robot would be any engineering piece, programmable by a computer, capable of collecting information from its environment via sensors and answering thanks to a set of automated actuators. It is, therefore, necessary to distinguish an authentic robot from an automated software (popularly called bots) that would not be considered robots themselves, although they can be very sophisticated.

From a historical perspective, we can look back the legends from classical Greece or ancient China about the animated mechanical models of various animals, or the golems from the Jewish tradition and even the automatons: recreational pieces very popular in Europe during 19^{th} century. But these constructions lack an adaptive response to their environment.

The term *robot* associated with artificial creatures first appeared in 1920, in the play "R.U.R." (acronym for *Rossumovi Univerzální Roboti*) by Czech author Karel Čapek. In this play the *roboti* (deriving from the Slavonic word *robota*: forced labour) are artificial servants of humans, who end up rebelling and extinguishing humanity. Although in the Čapek's play those servants are not mechanical beings (today we would call them androids or clones), the name *robot* is finally adopted as a modern version of the classic automaton from this moment onwards.

Following this thread and in accordance with the adoption of the term *robot*, in 1941 the notion of *robotics* appeared with the American novelist and professor of Biochemistry, Isaac Asimov. The neologism, first mentioned in the short story titled "Liar!" (published in the *Astounding Science Fiction* magazine), is widely used in all his later literature, dedicated to exploring the limits of artificial intelligence and its impact on human society of the future.

Practical applications in everyday life

According to the EU reports on Robotics, the benefits of their development would have a positive impact on several areas:

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

Educational connection

In the educational field, during the 80s, turtle robots associated with the Logo programming language were developed. Later, towards the end of the 90s, the company Lego presented the *Cybermaster* robots, developed to be used in schools, which were upgraded until *Mindstorms* NXT version in 2006 and *Mindstorms* EV3 in 2013. Currently, because of reducing the electronic components, there are multiple options to monitor all types of sensors with Arduino or Raspberry Pi technology.

From a pedagogical point of view, the Robotics applications in the classroom allow us to work on aspects that can hardly be addressed only 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 face up inaccurate data, variable stimuli and imperfect elements. For this reason, it is necessary to learn to design strong solutions for real problems in multidisciplinary projects.

Other positive aspects of the use of robotics in the classroom are more transversal, such as the students motivation, because it is a practical and experiential approach and can be seen as a game. Sometimes, the student's interaction with the robot can be used to work on convivial aspects and to reinforce social 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 for simulate human expressions as Aisoy (https://www.aisoy.es/), allow students to organize small theatre plays involving robotic actors. This 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

It is about programming a robot to cover certain distance and be as close as possible to a mark or a wall. Students should give orders to the engine systems and optical or proximity sensors to decide when to stop the robot. This exercise shows student 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 impellent device.

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REMOTE VIRTUAL LABS

> ***In these simulated spaces, students can operate with sophisticated and/or dangerous instrumentation in safe conditions and face (although with restrictions) the challenges that would be posed by an experimentation in a real lab.***

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Underlying principle

The scientific paradigm is focused on largely empirical base, and science education must include experimental elements. Many of those practical activities can be done in daily spheres, such as classroom demonstrations or field trips, but all educational establishments should have a lab: a space dedicated exclusively to experimental sciences and properly equipped.

Equipping a lab is no easy task: scientific instrumentation are often expensive, delicate and also toxic or dangerous if mishandled. For this reason, teachers with a solid preparation, flexibility to work with small teams and adequate funding are needed. And despite that, many concepts shall not be tested because of 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, more and more focused on research and innovation.

Fortunately, technological developments have enabled to create interactive simulations that runs in a more or less sophisticated way, as an authentic virtual lab. In these simulated spaces, students can operate with sophisticated and/or dangerous instrumentation in a safe conditions and face (although with restrictions) the challenges that would be posed by an experimentation in a real lab.

At the same time with the virtual world, there also exist the so-called remote labs, physical premises which can be remotely operated to give 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 very few and their activities are very limited.

In order for a virtual or remote lab to be pedagogically effective, students must be attracted to it. That is way 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 purpose.

Historical background of Virtual and Remote Labs

Virtual Labs

It is not easy to define the history of simulation as an educational element. However, the first simulations were made using physical elements, such as dolls used in the 60s in medical schools for lung resuscitation practices.

The popularisation of computers in the 80s, together with the appearance of high-level programming languages, allowed the first reality simulations, especially flight simulators widely used in the flying schools. Those simulations reached the general public with a game-oriented character, such as the pioneering Flight Simulator de Microsoft (1982). In 1989 Maxis launched the first edition of Sim City, an urban simulator, which is 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, kept them in the dark.

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

Remote Labs

Like in the case of virtual labs, remote labs history 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 to operate for a non-experimented user.
In the research made about the subject, platforms dedicated to their dissemination and broad repositories have not been found.

Practical applications in everyday life

Virtual labs are designed as an educational complement, so the applications in the life of citizens are derived from the fact that they have come into contact with such applications throughout their time at school and/or university.

In this sense, the direct benefits of this technology would be the same as those in the physical lab, such as:

- Implementing research methodologies in daily life. A paradigmatic case is the breaking out of new cuisine, with great influence of laboratory-based techniques.
- Using 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, allow 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 curriculum academic, as well as transversal skills. In many cases visual resources used in these systems allow the formation of a mental image of processes that are difficult to transmit. However the consulted experts put stress in the need of having highly specialised and trained teachers for these tools to have a real pedagogical sense.

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

But we can find some very remarkable elements in the transversal skills area:

- Students' motivation. The strategies of gamification and 3D immersion, 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. It is expected that group of students will soon be able to interact in the context of virtual labs, taking rols and working together to carry out research.
- Familiarisation of digital environments. The fact of developing 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 they are complementary tools for the school labs, which cannot be abandoned.

Practical examples

Virtual Labs

There are a large number of online virtual labs. Many are free-access simple simulations or more-or-less 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 H2020 programme, dedicated to IBSL (*Inquiry Based Science Learning*). In their school labs you can find a large number of interactive activities focused on various scientific aspects. It also includes a tool for teachers to design and share their own virtual labs, adapted to their particular teaching.
- **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. You 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 have several virtual labs. Experiments are focused on engineering, physics and chemistry. Activities are performed in 3D virtual reality environments, design with an open source software called OpenSim.
- **Virtual Engineering Sciences Learning Lab** (VESLL) is a virtual space created in the SecondLife platform, where users can develop 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 fee-paying.

Remote Labs

Faulkes Telescopes [http://www.faulkes-telescope.com/] is a network of robotic telescopes to be used by students and teachers for free. Anyone can book a time of operation of one of the multiple telescopes throughout the world to obtain real astronomical images and use them in the classroom. The fact that there are instruments in many locations allow to make observations of the nocturnal sky during classroom.

VISIR [http://ohm.ieec.uned.es/portal/?page_id=76] it is an automatic breadboard where the student of subjects linked to electronics can remotely test the result of a real wiring.

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EDUCATIONAL VIDEO GAMES

> *… games may put important social mechanisms at work, such as problem solving, empathy and team working…*

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Underlying principle

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

In a similar way, but not quite the same, there is the Game Based Learning (GBL). In this approach, board games, cards or video games are used to actually learn and practice the key concepts of the subjects, and not just to motivate the students.

Both strategies have the ability to improve the classroom dynamics and can be implemented in many ways, online or offline. However, in this report we will focus on the technological side of gaming and review educational video games only.

The main principle behind gamification and GBL is thought to be the dopamine rush. Dopamine is the neurotransmitter used by the brain to control the will (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 centers of the brain, once the action is accomplished.

Thus, as long as the challenges and the rewards offered keep being meaningful to the student, gamification and GBL can improve the student's 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 make any kid just learn. A well-planned, teacher-driven educational process behind gamification and GBL is paramount.

Historical background of educational gaming

Despite some acknowledge Pac-Man as the first educational video game, its intention was just pure entertainment. However, Pac-Man put at work many characteristics of an educational game, such as simple rules, obvious rewards, sense of excitement and puzzle solving.

Many regard the first educational video game to be the Logo programming environment (1967). It might not be intended to be a game, but 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 today) to teach the fundamentals of computer thinking and mathematical concepts in a funny way.

With the popularization 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 Sandiego?" (Geography) were some of the first video games with educational intention produced during the 1980s. Some became really popular, especially in the US.

Computer performance increased during the 1990s and video games gained interactivity and complexity. Many games simulated realistic environments, like "Sim City", "Sim Earth", "Civilization" and several kind of flight simulators, exploiting the basics of virtual reality. However, many of those evolved into arcade games upon time and lost part of their former educational purpose.

During the late 1990s and the 2000s, home consoles took over most of the gaming for kids off from personal computers. PlayStation, Xbox and Wii released educational games as a means to attract a family audience and not just the usual teenage gamers, like "Brain academy" or "MineCraft".

Since 2007, with the introduction of the iPhone and the popularization of mobile devices, most of the educational games turned 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 the players that must be solved by using a set of predefined tools and rules, agreed by everyone. Thus, games may put important social mechanisms at work, such as problem solving, empathy and team working, depending on the game.

In 1786, Benjamin Franklin published an essay entitled "the morals of chess" comparing the 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. A team of Dutch researchers published in 2013 a review of research on the benefits of playing video games. They claim there is evidence supporting the idea that modern video games develop a set of various 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 not much appealed by technology might develop some skills on computer usage and get familiar with virtual reality or augmented reality, that wouldn't otherwise.

Educational connection

Most of the educational connections already considered for the virtual labs, apply to the video games just as good.

In the particular field of STEM based video games, however, the experts agree on the importance of engaging the students in activities showcasing the scientific practice. On this regard, gamified virtual labs would be the best approach from the educational perspective, mostly when it's immersed into a virtual reality environment.

Quiz games have become quite popular during the last years, especially since the introduction of the mobile platforms. Many are tagged as "educational apps" at the Google Play or App Store, but lack a relevant educational impact since their focus is the content already learnt by the player and no new abilities are practiced.

This notion is consistent with the idea of "learning by doing" and one must keep in mind that indeed, video games can help practice and acquire some basic concepts, but the deep aspects of a subject still need the interaction with a teacher to be fully understood.

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

Practical examples

Learn Science [Nintendo DS]. In this game for the Nintendo portable device, the gamer can play minigames based on diverse aspects of science. The progress is mainly practical, with demonstrations and puzzles to be solved, and rewards can be obtained. There is a social side either, since one 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 your opponent's success.

Spore [PC, Mac and Nintendo platforms]. Design a creature and develop it through different evolutionary stages, from cell phase to full civilization and space exploration. Each stage let you explore and modify the fundamentals of the universe at your will.

Manga High [Any platform https://www.mangahigh.com/en/]. Somewhere in between gamification and game based learning, it 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 amongst 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 succsessfully.

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LOW COST EXPERIMENTATION

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

Underlying principle

The basic grounds for low cost experimentation is science popularization. The idea that science is an activity, rather than a set of facts or concepts, imply that anyone must be allowed to experiment on the natural rules on their own, anywhere.

The downside of this challenging idea is that, sometimes, expensive lab materials are needed to see a particular 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, arising in the USA during the early 20th century. Its maturity came at the 1960s in the punk scene in the San Francisco area. The original DIY community wasn't meant to explain the science behind any phenomenon, but rather to get some object built out of the market. The movement was actually somewhat countercultural and critical with consumerism. However, as the projects grew in complexity, engineers from various areas started sharing their technical knowledge with the rest of the community.

Science popularization as we know it today, began at 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 wonderful story about science, not science itself

One of the first science shows with hands-on activities aired on TV was the 1992 "Beakman's World". Inspired on a 1991 comic strip from Jok Church and directed to a fairly young audience, barely teenagers, Paul Zaloom performed the role of an extravagant scientist offering demos of various physical or 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 fully encouraged.

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

Practical applications in everyday life

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

Thus, the design and development of low cost experiments (and its proper dissemination), may turn our societies more rational, less superstitious and more critical.

Educational connection

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

On the other hand, experimentation tend to be multidisciplinary and many of the experiments that can be done with common things develop concepts from many subjects, such as physics, chemistry, biology, mathematics and technology. Building bridges across disciplines at school turns the 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 into planning and performing this kind of experiments reinforce 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 the 3rd law of kinematics as proposed by Newton.

Plants see the light [http://www.untamedscience.com/biology/plants/phototropism/]: plant some seeds into a box with a small opening in one side and wait for them to hatch. 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 pill of Mentos into a soda, the tiny pits on the surface of the pill will serve as nucleation points for the CO_2 dissolved. The rapid formation of bubbles at these points makes the whole bottle burst with a powerful stream. This is an evolution of the old experiment with bicarbonate and vinegar, but the principle behind is much different.

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EMERGING TECHNOLOGIES

3D PRINTING

> ***3D printing should be regarded as a productive tool capable of being used in all subjects which include parts of design.***

With the participation of Joan Alemany (Graduated in Maths in the Politechnical University of Catalonia, co-founder of eSeeCode. Secondary school teacher) and Frank Sabaté (school teacher specialised in STEM).

Underlying principle

3D printing is the group of processes allowing the fabrication of physical objects from an computer model, entirely designed in a software assisted by a computer (CAD) or fruit of a scanner 3D.

This kind of printing can be classified in the paradigm of additive construction, where the piece is the result of the positioning of the modelling material, layer by layer, until the final object is made (like in the construction of a building). In contrast, subtractive construction implies the casting of an initial piece till only leaving the final object (like in classical sculpture).

To achieve this additive effect, semi-solid or solid materials must be used with a 3D printer, an automatic and programmable tool able to work with volumes and not only on surfaces, like a traditional printer.

Therefore 3D printing principles are based on one side on those elements of computing and programming allowing the development of 3D design assisted by a computer, and on the other side on mechanical and engineering elements which have led to the fabrication of 3D printers strictly speaking.

Historical background of 3D printing

The main three-dimensional printing systems were originated in the 80s by Dr. Hideo Kodama, from the Industrial Research Municipal Institute of Nagoya, in Japan. Kodama developed the precursor of the current stereolithography system (SLA). The first patent for this system belongs to the American inventor Charles Hull in 1984, who begins the commercialisation of the first 3D printer based on SLA-1 of 3D Systems in 1987.

A year later, in 1988, Carl Deckard presented the patent of the SLS, a new way of 3D printing based on the fusion of dust particles. In 1992 the firm Stratasys commercialises the first printer based on the deposition of melted materials (FDM), becoming the standard of the most popular 3D printers among the amateur public because of their low cost.

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

Practical applications in everyday life

In professional circles there exists an agreement, also among the consulted experts, in that 3D printing will shake up the productive sector at an international scale. Logically it will also transform the global economy.

Though difficult to predict, everybody believes that the capability of fabricating practically any object, in a broad spectrum of materials, will place us in a future where the majority of daily consume products will no longer be bought in physical shops but will be printed directly at home. In this way, the final user of a product will purchase the design directly from big online shops and implement it in their own printer.

From this point of view the practical applications of 3D printing to daily life would be immense.

Educational connection

The above-mentioned implications in daily life spin around the capacity for the citizen to produce the most basic consumables locally. There is no, thus, need to learn but only to choose amongst the diverse models that the market can offer.

From a pedagogical point of view, however, 3D printing implies an interesting challenge. The consulted experts are worried about the current tendency to avoid using the capacities of 3D printers as learning tools in favour of using those of 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 pedagogical objectives before starting 3D printing activities in the classroom.

3D printing should be regarded as a productive tool capable of being used in all subjects which include parts of design, for instance:

- Engineering and technology, with the fabrication of pieces to the construction of models or mechanical or electronic devices previously designed in the classroom
- Mathematics and geometry, with the capability of visualising in the space shapes and abstract figures obtained through theoretical proceedings
- Plastic and artistic expression, with the possibility of designing and fabricating *atrezzo* pieces for theatre or creative structures.

Practical examples

There are diverse 3D printing technologies, each one with its own strengths and weaknesses, adapted to the diverse uses of destination of the printed object. The most used examples are:

Stereolithography (SLA). The original material is a viscose liquid able to solidify when exposed to an intense ultraviolet radiation. The construction of the model is made on a container of this material, which has a motorised platform. A laser emits a beam of ultraviolet light with the shape of the first layer of the figure (inferior), thus fixing the first sheet. The platform goes down to sink the model in the material again and afterwards the second layer is radiated, being united to the first one. And so successively until the finalisation of the model.

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

Selective Laser Sintering (SLS): From a mechanical point of view, SLS shares similarities with SLA. but in this case the original material is a nylon in dust (though it also can be of other materials like polystyrene, ceramic materials). The laser heats up the first model layer on the dust nylon so that the particles, very small, are melted. Immediately the motor platform goes down and a brush places a fine film of dust on the layer to start the second layer of the model. At the end the remaining nylon dust is extracted with pressurised air.

The main advantage is that the melted nylon is very resistant and the pieces made with this technique can be functional. Besides, since nylon in dust is solid, there is no need for printing support structures in the model.

Modelling through deposition of melted material (FDM). There are diverse possibilities in this case 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 the space. Generally the process goes bottom up.

Since all the components are basically mechanic, without lasers nor sophisticated elements, it is the most economical solution and thus closer to non-professional users. However the quality of the models is lower than those of the SLS and SLA systems, because the thickness of the thread determines the resolution and the maximum detail that can be achieved.

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OPTICS AND PHOTONICS

> ***… there is no easy way to introduce the very nature of light and its properties into the school curriculum… light is non intuitive. As such, it must be taught with extreme caution and with an educational plan in mind.***

With the kind participation of Víctor Grau (PhD in Physics; tenure professor at Universitat de Vic, arts and sciences didactics department).

Underlying principle

Optics and photonics are closely related branches of physics, both concerning the study of light and its behavior. Optics can be considered the classical framework from where photonics emerged upon discovering the quantum nature of light.

In a very simplified way, light can be described as an electromagnetic wave *and* as a beam of tiny particles called photons. From the perspective of a wave, light moves through the 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, accounting for its color.

However, light is much more complex than that and should not be represented like a classical mechanical wave, as can be found 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 show properties not seen in classical waves, such as the photoelectric effect, accounting for individual impacts of photons on a detector, or the light produced in a 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 a bit of a controversy on the beginning of optics. A 3000 years old lens-like object was found in Nimrud (today's Iraq), pointing at the Assyrian culture as its first developers. However, there is no consensus whether it was actually used as a lens or it was just a piece of furniture.

We know for sure that the ancient Greek and Roman cultures used water filled glass spheres as lenses and developed some theories on the propagation of light. Actually, the term *optics* comes from the ancient greek *optikē*, meaning *appearance*. After the fall of the Greek and Roman civilizations, the development of optics continued in the Arab and Indian worlds, with key treaties on the field being produced.

It is noteworthy that the earlier theories did not represent light appropriately and, while describing properties like reflection or refraction with some detail, failed with the description of what could emit light and how images were formed in our mind. On 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 the bitter discussions between Newton and Hooke, two of the most renowned physicists of all time, upon the very nature of light as a bundle of particles (Newton's model) or as a wave (Hook's model). Both interpretations coming from the earlier works of Kepler 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 the experiments of Young and Fresnel on the indisputable nature of light as a wave and, lately, with the Maxwell equations showing light from the electromagnetic point of view.

Planck, Einstein and Bohr, during the 20th century, completed the theory of light as a wave and a particle at the very same time, and setting the start point of a new field: quantum optics. The invention of the laser in 1960 is regarded as the starting point of photonics, dealing mainly on the study of photons, its physical properties, its production and its interactions with matter.

Practical applications in everyday life

We humans are daytime creatures and, as such, light is all around us most of the time. We make decisions based on optics quite often, like painting a room with light colors to maximize 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 the 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. Particularly considering the massive use of smartphones and the photo/video sharing apps nowadays.
- Today, many devices we use are based on light, such as remote controllers, motion detectors and proximity sensors.
- Identifying optical effects, such as mirages or other deformations due to reflection and refraction of light.

Educational connection

According to the experts, there is no easy way to introduce the very nature of light and its properties into the school curriculum. The key would be to start with the particle-like model during primary school (6 – 12) and proceed to the wave model during the secondary school (12 – 18).

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

- Biology: optics and photonics help explain the basis of photosynthesis in plants, the color of flowers and the physiology of the eye.
- Philosophy: the very idea of *seeing* may pose some philosophical sides, such as the subjectivity of beauty.
- Arts and humanities: many artistic expressions are light depending, like the aforementioned photography, but painting, architecture or performing can be greatly influenced by light as well.

Practical examples

One of the most important issues raised by the experts when it comes to teach optics and photonics, is the notion that light is non intuitive. As such, it must be taught with extreme caution and with an educational plan in mind.

Hence, not any practical or analogy would do. A strong recommendation is to set a strong basic knowledge on the so-called classical optics:

Light propagation – The idea that light travels from point A to point B in a straight line. This might be obvious by 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, easy to introduce from the perspective of a beam of particles.

The idea of detection and vision – Light is not emitted by our eyes, but reflected by objects in the path of a light source instead.

After the basic understanding has been set, the advanced concepts can be introduced in the later courses before college:

Wave model of light – Diffraction/interference and color as wave-related properties of light.

Polarization – The angle of rotation of the electromagnetic wave and how can it be modified or constraint.

Quantum theory of light – In a limited way, the notion of photons as 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 benefit in building bridges among the various disciplines in STEM.***

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

Underlying principle

Nanotechnology regards to any technological activity conducted at scales around 1 to 100 nanometers, being 1 nanometer (1nm) one thousand millionth of a meter (or one billionth if using the short scale). This is the scale of atoms themselves, as the diameter of helium is about 0,1nm.

Thus, nanotechnology applications are those that provide extreme miniaturization or use and rearrange individual atoms at will. Engineers are finding impressive new properties of materials at the nanoscale, such as enhanced strength, reduced weight and color variations related to size. Similarly, many properties of known materials, such as conductivity or magnetism, show unexpected behaviors when reduced down to its fundamental molecules.

In order to do these kind of manipulations, specialized tools have been developed, such as high resolution Transmission Electron Microscopes (TEM) or Scanning Tunneling Microscopes (STM), powerful devices to actually “see” the atoms. On the other hand, Atomic Force Microscopes (AFM) are capable not just to “see” but to really move atoms around.

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

Historical background of Nanotechnology

Practical effects of the nanoscale have been observed along history. The color of many pigments relate to tiny nanoparticles within. The strength and flexibility of the Damascus steel blades are thought to be related to the formation of carbon nanotubes during the forge. However, these observations remained largely unexplained for centuries.

The idea that the nanoscale was available for experimentation and that atoms could be rearranged at will, was firs addressed by Richard Feynman in his inspiring lecture at Caltech in 1959 “There is plenty of room at the bottom”. This conference is regarded as the origin of today’s nanotechnology, being the term first used in 1974 by Norio Taniguchi.

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

The development of nanotechnology has been very dependent on the ability to see and manipulate things at the tiny scale. Thus, the landmarks for its implementation correlate with the invention of the scanning tunneling microscope (STM) and the atomic force microscope (ATM), both at the beginning of the 1980’s.

This new technology, capable of rearrange individual atoms, was put at work in 1989 for the first time, when IBM - developer of the scanning tunneling microscope - used such a device in a stunning demonstration, writing their acronym with 35 xenon atoms on a nickel surface.

Many have been discussed about the potential uses of atomic rearrangement, like nano-engineering and nano-robotics. However, little applications exist and it is a field still under development.

Most of the current advances on nanotechnology refer to nano-coating of surfaces with metal ions, such as silver or gold, to provide existing materials with enhanced properties, or the design of new molecules with self-assembly capabilities to build structures bottom-up, just like biological structures do.

Despite the huge benefits promised, some concerns have arisen from the use of nanotechnology in the recent times. Heavy metals, such as silver or gold, are known to be carcinogenic when ingested or inhaled. In a similar way, some evidence suggest that carbon nanotubes might be as harmful as asbestos in our lungs.

Practical applications in everyday life

Current nanotechnology applications are mostly being used in mass production and industry, such as miniaturization of electronic components or catalysts to capture harmful molecules and reduce pollution. The average citizen is not much aware of it and, thus, the knowledge of the nano world remains a bit irrelevant in the daily life.

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

Educational connection

Since nanotechnology lies somewhere between physics, chemistry and technology its study could benefit in building bridges among the various disciplines in STEM. In particular, when the approach is practical, kids can experiment on magnetism by using ferrofluids (and see the magnetic field in 3D) or consider the daily applications of superhidrophobic materials at the classroom.

On this regard, some efforts have been made to deliver activities on nanotechnology at school. The “Nanoeduca” toolkit for secondary school (available internationally upon request) is a good example of these efforts, and provides all the necessary materials and instructions, as well as a full educational plan to integrate the activities at the classroom.

The experts contacted agree that the activities on the nano world are very welcome, both by students and teachers, and the feedback received is very positive. On the teachers’ side, in fact, the possibility to approach the 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 go far beyond the STEM paradigm and sometimes fall into 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 superior to the risks?

Other issues around nanotechnology that can be considered at the classroom are those concerning the rationalization 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 pieces of art, such as paintings. Not only can these materials merge more naturally with the original objects, but they can prevent future degradations better than traditional methods.

Characterization of materials: the imaging techniques developed for the study of nanomaterials are of use in other fields, such as the identification of materials found in a crime scene or assessing the author of an art piece.

New pigments: some nanoparticles show one color or another depending on its size. This have led to the development of nanodyes for many applications. The Quantum dots, for instance, are used in molecular biology to tag proteins and other molecules into the cells and study their localization.

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

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

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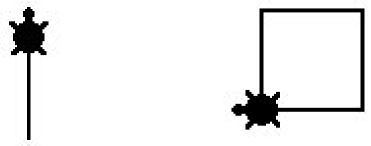
ANNEX

ANNEX I

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

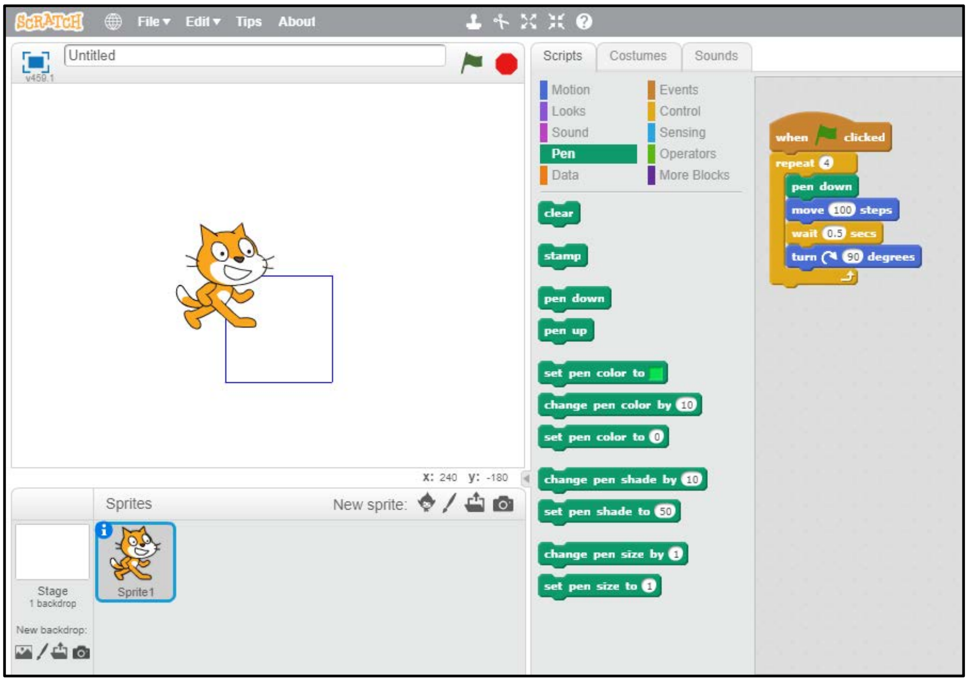
Use **Logo** to draw a square of 50 pixels' side using a repetition loop. The language is simpler and there is little syntax.

```
to square
repeat 4 [forward 50 right 90]
end
```



`forward 50`   `4x right 90`

Use **Scratch** to draw a square of 100 píxels' side, using a repetition loop. As it can be observed, 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 of 100 pixels' side. In this case no loop is used since the rectangle is directly defined. It can be observed that the language is much more complex, with a non-intuitive syntax and integrated functions (like *document* or *var*):

```
<!DOCTYPE html>
<html>
<body>

<canvas id="myCanvas" width="300" height="300" style="border:1px solid
#d3d3d3;">
Your browser does not support the HTML5 canvas tag.</canvas>

<script>

var c = document.getElementById("myCanvas");
var ctx = c.getContext("2d");
ctx.rect(100, 100, 100, 100);
ctx.stroke();

</script>

</body>
</html>
```