STEAM IMPLEMENTATION GUIDELINES

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INTRODUCTION

What it is known as STEAM disciplines offers a unique opportunity for involving pupils in processes similar to those produced in science: inquiry, experimentation, modelling, argumentation… Participation in all these research practices helps pupils to understand how the scientific knowledge is developed. Therefore it is necessary to approach science and technology knowledge in a global way.

In this guide, thus, a set of applicable technologies to this learning context is presented. Previous considerations for their application are analysed for each one, directions of how to use them in the classroom and good practices examples are also given as an inspiration for implementation.

This guide is the continuation of the report ‘State of the Art of Stem technologies’. Both make a unity and are worth consulting jointly. The reports have been made in the framework of the sySTEAM project financed by the Erasmus + Programme of the European Commission.

General directions: how to work STEAM projects in the classroom

These guidelines present diverse technologies applicable in the classroom and each of their peculiarities. But beyond their own characteristics, there are common features.

This introduction intends to present basic pedagogical recommendations to deal with STEAM teaching in the classroom successfully, which are also applicable to any technology.

Pedagogical recommendations:

1. Adapt the classroom. A proper place for the pupils to work on the experiments and in teams to share ideas, write and or debate must be prepared. Besides, the necessary material should be provided according to the design of their research. 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.
2. Formulate proper questions. Teachers should make sure that the questions formulated by the pupils or by them encourage to deepen their reasoning, avoiding the ones that can be answered by simple definitions. Furthermore, it is necessary to set up an atmosphere in the classroom where everybody can state their own opinions and can answer questions without fear of being wrong.
3. Know pupils' prior ideas. Many times pupils have already prior knowledge about certain phenomena which can be wrong or incomplete. The teachers' task will be to know, complete and rebuild them so that they are scientifically more accurate. For this, it is good to start each new research with debates about what the students think of that 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.
4. Organise group debates. In this way, the students can share their ideas, see different points of view and learn from other classmates. But these debates should not be carried out in a spontaneous way, on the contrary, it is necessary a previous training in the debate culture. Respecting speaking times, thinking over a few seconds before speaking, considering what it is wanted to be said, or being able to obtain conclusions from the debates are skills which must be worked in advance with the pupils. Likewise, the teachers' task should be that of the starter and guide of the debate but allowing the pupils some autonomy to discuss among them.
5. Elaborate final products. It is necessary to create different materials which allow the pupils to register all their research process and thus be able to realise what they have learnt and how. Besides in this way the teachers can consult them to analyse whether the pupils' learning has been suitable and, accordingly, to better orientate them. These products can be lab notepads, experiments protocols, oral presentations, posters. It should be considered to provide them with models of different products so that they can learn to make them. Also, when reviewing the products, the teachers should be careful not to centre in the detection of misspelling or syntax but also in guiding them in the reasoning and fruitful commentaries.

Inquiry-based teaching

For introducing STEAM concepts in the classroom it is recommended to apply the inquiry-based teaching, a way to teach science based on the importance for the pupils to really understand what they are studying. IBSE avoids the superficial learning that memorising information and concepts imply.

Research on science didactics shows how the students, from an early age, have a great curiosity in all things surrounding them and are able to elaborate explanations about phenomena they observe in their daily lives. IBSE intends to give continuity to this curiosity and help the pupils' spontaneous explanations to be transformed into more scientifically accurate formulations through well-structured activities.

Besides IBSE allows the students to work in a similar way of that of the scientists to avoid science lessons from being understood as a mere way to consume science products, but instead 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. So the idea is that pupils are not limited to repeat the already established outlines made by teachers, but to allow them to explore, research, make conclusions and ultimately to communicate what they have learnt.

For doing that it is required to understand pupils' context and interests to design activities and experiences according to their level of knowledge and which allow them to be motivated and make them think about their surroundings' phenomena.

Bearing in mind that IBSE can be undertaken differently depending on the tools, skills and teacher's knowledge, a series of general considerations and pedagogical recommendations to follow will be given down below.

Basic considerations about IBSE:

1. Direct experience is important. Pupils should be allowed to directly experience the phenomenon there are researching. Research on learning tells us that pupils, outside the school, learn and build concepts from direct experience with what surrounds them. For this reason, it is necessary that in the classroom the same happens: The possibility for the pupils of questioning their prior ideas through the formulation of new questions from different experiments should be facilitated.
2. Question as a starting point. Pupils have to understand that their starting point in their research should be a question. A way to motivate them and that they feel involved in their research is giving them the opportunity to raise that question themselves so that it becomes the most meaningful for them.
3. Need for learning different skills. To carry out their research the pupils must be capable of observing, making questions, predictions, designing researches, analyse information and formulate statements based on evidence. The teachers' task will be to guide them during the whole process.
4. Far beyond simple experimentation. Science classroom should not be about undertaking hands-on experiences but about asking pupils to reflect on and discuss what is being produced. Debates about the experiment can be organised, in this way ideas will surface which can be written and be perfected.
5. Use of secondary information resources. In IBSE it is necessary to go to other information resources beyond direct experimentation. Books, the Internet or even experts should be consulted to complete the missing information in their experiment.

6. Science is a collaborative activity. Pupils should work in small groups to share ideas, debate and think with their classmates in the same way professional scientists do. Teachers must create balanced and cooperative groups to better favour a proper work atmosphere so that each can make contributions according to their capacities.

PROGRAMMING

> ***Programming cannot be an exclusive matter of the technology or engineering areas… It is necessary that educative centres are organised in a way that all disciplines contribute for pupils to be able to programme.***

Objectives

Computing practice has recently earned its place in the academic curricula and it is included in the educative standards like K12 Next Generation Science Education Standards. This is because programming, more than a purpose by itself, to learn certain computing languages, is considered as a means for the pupils to participate in processes similar to scientific activity.

Thus programming in the classroom intends that pupils:

- Are capable of building models of the surrounding phenomena through the abstraction of concepts
- Acquire the capacity to solve problems since programming allows them to realise nearly in an immediate way whether the programmed order is correct or not
- Develop creativity and imagination
- Know different programming languages, for instance, Schartch or Processing

Pieces of advice for its use in the classroom

Whether programming is used in the classroom as a means or as an objective, the pieces of advice the experts give are common. The following ones can be highlighted:

- Separate digital language from science to be learnt. First of all, programming must be learnt to know what kind of things can be explained. Teachers can start by asking pupils to programme games (like video games) or animations where different characters interact, something that will motivate them at the same time that it will allow them to get familiar with the functioning of the software.
- Be incremental. From one side, if it is intended that the students programme a certain model of any natural phenomenon, then simple processes should be started by, 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. On the other side, if an activity for the students destined to know the functioning of different programming languages is to be implemented, then it is also recommended to start by simple tasks which do not imply many orders so that the pupils get familiar with them step by step.
- A transversal tool. Programming cannot be an exclusive matter of the technology or engineering areas. It must be transversal to all subjects. It is necessary that educative centres are organised in a way that all disciplines contribute for pupils to be able to programme.
- A tool for workplace diversity. Programming allows each pupil to work in an autonomous way, meaning that everybody can learn and work on their own rhythm. For this reason, it is important to establish clear objectives when planning activities, bearing in mind that pupils

will have to start always by outlining their model on paper and not without any prior scheme. For instance, when programming a game first, it is vital that rules are clear, when programming an animation an outline must be made, and when explaining a natural phenomenon it is necessary to know what factors intervene.

Considerations before its implementation

First, teachers will have to know and control the programming software to be used. It is recommendable to try different ones to see the possibilities that each one offer. The most simple ones which Secondary pupils can use are Scratch (it is not necessary to know programming language), Processing (with a syntax based on Java but approachable to non-experienced programmers) or a variety of Scratch called Arduino (for programming in robotics). All of them are open code and affordable to any school.

Secondly, frustration among pupils will have to be watched and a balance must be found since, in the sequence of the activities, the provided guidelines phase will be followed by the autonomous phase. Teachers must find the just point of intervention. It is recommended that in the first moment all pupils can work on the same activity and take different paths afterwards according to their objectives. In this sense, it should be avoided that programming becomes an obstacle for the pupils to model a determined phenomenon.

And last, it should be taken into account that the STEAM paradigm can only be attractive to a certain pupil's profile (male and with a specific background and with a certain interest in science), so the challenge for the teacher is to engage other pupils' profiles as well. All this implies that it activities linking programming with different fields and social issues should be implemented.

Resources

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

Processing [https://processing.org/] (Software Processing website with tutorials, guidelines, and examples for their use)

Scratch for Educators [https://scratch.mit.edu/educators/] (On the website part dedicated to teachers there are tutorials, guidelines and also working online with students)

BRENNAN, K., RESNICK, M. (2012). New frameworks for studying and assessing the development of computational thinking. In Proceedings of the 2012 annual meeting of the American Educational Research Association (pp. 1–25). Vancouver.

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, 615–641.

Practical examples

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

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

ROBOTICS

Experts recommend … to implement activities which generate transcendence, which are useful for the pupils to realise that engineering nowadays is developed with the participation of interdisciplinary teams with the goal of giving solutions to the social problems and needs.

Objectives

Robotics, because of its need to develop and materialise an idea, is a transversal discipline where different spheres intervene: Engineering, mathematics, physics, electronics, programming and design, even the software SketchUp for 3D printing domain. For this it is a very good option to work in different educational aspects:

1. To transfer abstract concepts to reality and make them more understandable for pupils
2. To favour the personal autonomy of the students and their capacity for solving problems since they are the makers of their own ideas
3. To awake students' scientific and technologic vocations
4. To allow pupils to work in groups and to improve the classroom cohesion.

Besides, it is nearly essential to work robotics from a global project point of view where the purpose of the activity is introducing a device which satisfies a certain need or improves an already existing one. Thus, the students connect with their surroundings more consciously.

Pieces of advice for its use in the classroom

From the starting point of the need for a global and inquiry-based work and to apply robotics in the classroom the following aspects should be taken into account:

1. Execution of progressive activities. Even though robotics objective is building an object that all students have to conceive to solve a need in their surroundings, it must be considered that previous skills are required, especially those in the field of programming. For this reason, the experts recommend carrying out small previous practices, with very simple guidelines, so that pupils perceive the correlation between programming and robotics and acquire the necessary knowledge to be applied later in their device building.
2. Organisation in work groups. A big part of the success and work progress in robotics projects lays in the capacity of the teachers in organising their pupils in balanced groups with different abilities and skills. If achieved it will be easier that each one can perform one concrete task: From group coordination to the explanation of the project to the classmates or having better Maths abilities or space vision. It can also integrate the pupils' diversity. The maximum recommendable number of pupils is 4.
3. Final products. Besides the product, as a result of the activities based on projects, it is convenient that a project memory is presented where all the technological process is detailed, an oral presentation in front of the rest of the group (as in science fairs or as if they had to sell a prototype) and a video showing the functioning of their robotic device (this is perfect in case that in the moment of the live presentation something fails and does not work properly).

4. Project assessment. It should be taken into consideration the items to be assessed during the robotics project since aside from its final result (whether it functions or not) the group coordination and individual participation should be regarded as well. Likewise, the pupils should be given the opportunity to assess the rest of the other projects, even voting for the best one. □
5. Transcendent activities. Experts recommend, as a complementary issue, to implement activities which generate transcendence, that is which are useful for the pupils to realise that engineering nowadays is developed with the participation of interdisciplinary teams with the goal of giving solutions to the social problems and needs. For instance, visits to Faculties and Engineering schools, enterprises or start-ups or even congresses and technological fairs could be organised.

Considerations before its implementation

Even though robotics practices could seem at the beginning complex, the experts coincide in that teachers should lose their initial mistrust and have the willingness to implement them. A good start would be that teachers undertake permanent training. Likewise, it must be taken into account that pupils have mental strategies which make working in this way easier: It is very proactive, attractive and facilitates teacher-pupil joint learning. □

For implementing robotics activities no big technical requirements are needed and this facilitates its use in the classroom. The indispensable needs are computers (laptops better for improving the flexibility of the space), robotic plates connected to them and the material that pupils will use to develop their projects. For this, it could be the same pupils who undertake the research of their own material or it could be the school which would give it to them and foresees having its reposition. □

Pupils must have minimum programming skills linked to the needed software. This point could have been worked in initial courses or in parallel from other curriculum disciplines. For instance, it is very useful that pupils have worked with Arduino since its simplicity makes it one of the most recommendable tools for the pupils to be initiated in robotics.

Resources

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

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

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

Sterling, L. (2015) “Five reasons to teach robotics in schools”, The Conversation, online article [http://theconversation.com/five-reasons-to-teach-robotics-in-schools-49357], Last consultation May 2018

Practical examples

Hackster [https://www.hackster.io/arduino/projects] (community dedicated to learning Arduino software which gathers examples of its use)

RoboESL [http://roboesl.eu/] (European project which uses robotics for preventing educational failure)

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

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

VIRTUAL AND REMOTE LABS

… under the name "virtual and remote labs" there are very different proposals, from small simulations to obtaining real data from research centres like CERN.

Objectives

The use of virtual labs, simulators and remote labs in the classroom has different purposes:

- To facilitate tools for making experiments and practices which normally cannot be carried out in the educational centres' labs owing to lack of equipment
- To carry out experiments without any risks and thus helping the pupils to reduce the aversion to making mistakes
- To help to illustrate phenomena or structures which are difficult to represent with traditional methods (blackboard for instance)

Nonetheless, it is recommended not to substitute offline labs with online ones since they are complementary tools. Besides, the students can resent the overuse of electronic devices (PCs, laptops, tablets).

Virtual and remote labs can be applied to different scientific and technical disciplines: Physics, Chemistry, Biology, Technology (Engineering) and Mathematics, with more possibilities to work in Physics and less in Mathematics. They can be also introduced at any moment of the didactical sequence.

Thus, this kind of technology fits perfectly STEAM methodology as it makes possible that pupils participate in the scientific process, encourages them by making science lessons more enjoyable and entertaining, aside from allowing to deal with the great diversity in the classrooms nowadays.

Pieces of advice for its use in the classroom

It should be stated that under the name "virtual and remote labs" there are very different proposals, from small simulations to obtaining real data from research centres like CERN. It is, therefore, an ensemble of heterogeneous tools and each proposal can require its specific approximation. A few pieces of advice to be offered are:

1. Simple activities and clear objectives. First, it is very important that the teacher designs simple activities with clear objectives for the pupils to achieve the best performance from these technologies. This means that despite the pupils can work in an autonomous way the

guidelines for the development of the proposed activities must be clear and understandable so that, in this way, the pupils can direct their curiosity and understand the need for systematising research.

2. Teachers' monitoring. Teachers have a guidance role during the activities even though the experts' recommendations say that not all the process should be controlled. It is recommended that the teachers stop the activity development from time to time for sharing issues and discussing the point where the pupils are. If not there is the risk that pupils simply play with the simulations without using them properly.
3. Obtainment of results. It is necessary to obtain a final product which can be a practice report or answering questions about that part of the scientific process wanted to be worked on. For instance, that pupils find a few initial questions or make hypothesis or write the conclusions of the experiment.
4. Proper use. Virtual and remote labs should be used when really necessary like, for instance, to simulate an experimentation which cannot be carried out at the school due to lack of means. Simulations should be a complement to real experimental activities, not a substitute for classroom experimentation.

Considerations before its implementation

A good Internet connection is indispensable along with pupils having computers or tablets, at least one per each couple. This facilitates the use of this technology in any class of the school.

The teachers must have enough time for planning and designing correctly the activities, avoiding in this way improvisation. Besides, for using virtual labs of GoLab an brief training to get familiar with Graasp tool is necessary.

GoLab laboratories have an excellent worked pedagogical environment, facilitating didactical units already programmed and easily applicable, although sometimes it is preferable to adapt them according to the pupils' characteristics and their educational context.

Resources

University of Colorado simulators [https://phet.colorado.edu/]

Go-Lab Project [https://www.golabz.eu/](well worked pedagogical atmosphere with labs gathered from around the world and with heterogeneous functioning. It allows to share and to adapt activities designed by teachers).

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

ChemCollective [http://chemcollective.org/home] (virtual labs for teaching Chemistry)

Vozniuk, A.: Enhancing Social Media Platforms for Educational and Humanitarian Knowledge Sharing: Analytics, Privacy, Discovery, and Delivery Aspects. Publication Publisher: École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, 2017. Online document [http://www.go-lab-project.eu/sites/default/files/files/publications/file/EPFL_TH7495.pdf] Last consultation: May 2018.

Practical examples

Faulkes Telescope Project [http://www.faulkes-telescope.com/] (a network of robotic telescopes which allows to obtain real astronomical images to be used in the classroom. It also provides examples of activities carried out by them).

Galaxy Crash [https://www.golabz.eu/lab/galaxy-crash] (Simulator of galaxies collision which allows the comparison of predictions made by students).

Vcise: Drosophila Melanogaster Genetics Experiment [https://www.golabz.eu/lab/vcise-Drosophila-melanogaster-genetics-experiment] (virtual lab which allows the application of genetic principles working with vinegar flies and observing the results of modification of heritage patrons).

EDUCATIVE VIDEOGAMES

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

Objectives

There is a great variety of examples of video games to be used in the science, technology and mathematics classrooms, like Arcade, sandboxes kind, quizzes kind, strategy kind, simulation kind, target practice kind… Its importance lays on the didactic focus given to them. In this sense, the experts distinguish between those ones dedicated to improving the classroom and those ones dedicated to doing better science.

This implies considering the objective of using video games in the STEAM sphere for the pupils to learn how to do science that is, using video games to deal with the three aspects of the scientific practice: Modelling, inquiry, and argumentation.

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

So without underestimating any other kind of video games, the most adapted to the premises of the new tendencies in science didactics gathered in the educative standards like for instance K12 Next Generation Science Standards (NRC, 2012), would be those games proposing an intellectual challenge to the pupils who should solve it by building a model or an explanation; the pupils could solve the challenge of acquiring new ways of doing they did not have at the beginning; present a reward system allowing the simulation of the social context of the scientific practice.

Pieces of advice for its use in the classroom

1. Consider in what moment of the didactic sequence the video game should be introduced. The great variety of existing typologies of video games makes it possible that any is used for working a different aspect of the scientific context. So the teacher's task is correctly sequencing the use of the video game to give it its sense in the learning process: Using it in the moment of inquiry, of structuration or of the application of knowledge.
2. Simple initiation. It should be taken into account that all pupils will have to be able to complete a minimum of the video game development and henceforth the progress in complexity will have to be facilitated. There are video games allowing the pass through different levels as gamers acquire the skills for solving more complex models or finding more elaborated answers and explanations.
3. Combine online and offline activities. Evidence in didactics research proves that only using online technologies or digital tools less is learnt than when combining on and offline activities, like for instance the so-called activities of paper and pencil or practical experimentations (hands-on).

Considerations before its implementation

The aspects to be taken into account are related to the own video games characteristics and what is intended to obtain with them. The experts highlight:

- Use of rewards. Despite the objective of the video game is competitive, rewards cannot be linked to a traditional teaching conception. Strategies recreating the conditions of people doing research should be searched. For instance, as the game advances points could be obtained for exchanging them for material to be used in one of the lab practices of the school centre.
- Elaborated solution. The video game should not be resolved by just a simple search on the Internet but by making complex answers which develop into other questions
- Not centring on purism. Pupils should be able to advance in the video game without the need of using specific language or knowledge. This means that it is not that important for the pupils to know a certain vocabulary but to be allowed to structure and relate concepts.
- Importance of the pupils' previous background. It is frequent that students play having in mind possible solutions which many times are incorrect or ambiguous and which the video game should help to reformulate.
- There are many digital platforms gathering different video games many of which can be played online thus facilitating its use in any space in the school centre without any specific technical requirement beyond an electronic device and Internet connection.

Resources

Brain Pop [https://www.brainpop.com/] (website dedicated to the use of digital tools in education presenting different resources like video games and simulations classified by themes and for any of them suggestions are offered in didactics and complementary material)

Physic Games []http://www.physicsgames.net/ (set of games based on physics and with different degrees of complexity)

Dragon Box [https://dragonbox.com/] (portal with different applications of online games which can be downloaded also for mobiles but for a fee)

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

Practical examples

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

Guts and Bolts [https://www.brainpop.com/games/gutsandbolts/] (video game where through several screens the games will have to make an anatomic model related to circulative, respiratory and digestive system)

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

LOW-COST EXPERIMENTATION

> ***Low-cost experimentation activities can be worked from all the subjects perspectives and can be applied to any moment of the didactical sequence.***

Objectives

Two are the main objectives for using this kind of technology in the classroom: First to do science (experimentation and inquiry) with the added value that the experiments are easily made, occupy little space, have low cost and can even be made at home. Second to involve pupils and encourage them to do scientific practice.

However, each experiment would have its own concrete objectives on which the derived activities depend. It is on the basis of this design that low-cost experimentation will be linked in a higher or lower degree to the different scientific and technical disciplines.

Low-cost experimentation activities can be worked from all the subjects perspectives and can be applied to any moment of the didactical sequence. At the beginning for looking into what the students think about a certain phenomenon or like an initial stimulus; other times it can be done in the middle of the sequence to explore what is happening or to predict what will happen; it can be done also after explaining a determined part of the curriculum by asking the students to interpret a low-cost experiment with the acquired knowledge.

Additionally, it should be taken into account that doing a low-cost experiment in the classroom does not facilitate by itself that the students behave like scientists. It is the task of the teacher that this option is offered by doing a proper design of the activity related to the experiment. It should not be about providing an already established and closed protocol to be reproduced but about encouraging the pupils to inquiry and question how and why.

Considerations for its implementation

This kind of experimentation is off-road and can be applied to any level of Secondary Education, bearing in mind that the level of interpretation of each experiment is different and goes according to the difficulty of the contents worked on each stage.

1. Previous test by the teacher. The experts recommend testing the experiment before carrying it out in the classroom with the pupils.
2. Use them frequently. This kind of experiments should be done regularly so that pupils get the necessary habits and get the norms which will allow them in the long term to work in a more autonomous way. It is also recommended to work in small groups between 2 and 4 pupils.
3. Design the suitable sequence of the activity. Low-cost experiments cannot develop into a replication of certain protocols previously facilitated by the teachers, instead they have to allow reflections, the pupils to think about how to carry out a certain demonstration, thus facilitating meaningful learning.
4. Obtaining results. It is important that there is a register, digital or on paper where pupils can think about the experiment and avoid that it is understood like a simple game. A whole lot of

final products can be asked: From a work with closed questions till a lab notebook where all the experiment steps are written.

5. Final assessment. It must have a double sense. On one side, assessing the interpretation and academic progress of the pupil, on the other side assessing the functioning of the experiment. For this, the experts recommend asking the pupils an assessment of the experiments conducted during the academic course. In this way, a very valuable feedback can be obtained by the teachers who can consider whether certain aspects or their approach to the experiment should be rectified.

Pieces of advice for its use in the classroom

First, teachers must be motivated since willingness is needed for conducting these experiments and lose the fear of malfunctioning. Secondly, a certain previous training is recommended to try and learn new experiments and thus getting motivated to their implementation. Certain online resources with low-cost experimentation can be consulted.

Likewise, its use must be rationed because sometimes the students tend to ask continuously to do them.

For the pupils to become familiar with the way of doing science and its method, it is necessary to design the activities in a very clear way, where different concepts are worked like hypothesis, conclusions, validation, etc.

Lastly, it must be mentioned that there are no big technical requirements to conduct these experiments in the classroom. It is recommended, though that the classroom has the flexibility to adequate space (tables and chairs not fixed on the floor). A few experiments can even be done outdoors.

Resources

Poppe, N., Markic, S, Eilks, I. “Low cost experimental techniques for science education” (2010), TEMPUS, European Comission. Online document [http://www.idn.uni-bremen.de/chemiedidaktik/salis_zusatz/material_pdf/lab_guide_low_cost_experiments_englisch.pdf]. Last consultation: May 2018.

Practical examples

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

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

3D PRINTING

> ***The experts recommend that having a 3D printer in the classroom be considered as a school project where different departments can work collaboratively and with a transversal vision of the activities and projects*.**

Objectives

The possibilities for 3D Printing as a tool to work under the STEAM umbrella are very big since it is a technology which allows to link different disciplines, engineering, technology, mathematics, artistic expression, biology or chemistry, but the teachers must have clear that the main objective must be for the pupils to design their own object to be printed.

In this way the pupils:

- Will give an answer to a certain need: It can be suggested by the teacher (to create a decorative object for the room, make contests for designing objects related to the school, obtain pieces for building a robot or other electronic device)
- Will be able to realise the viability of their designs, because often the pupils tend to design objects which 3 D printers cannot print. In this way, they will be conscious of how the technical limits are important for finalising engineering or research projects
- Will get the ability to make models as they will have to express their ideas and make drawings with the support of a suitable software.

For all those reasons the consulted experts agree on saying that working in the classroom with 3D printing is a good resource for the pupils to do science and technology.

Pieces of advice for its use in the classroom

1. Get familiar with the software for the design. The pupils should start at the early stages of Secondary education to get familiar with the use of software for designing things to be printed, like Scratch. A curricular continuity should be implemented in a way that as the pupils move forward in the courses also their needs to be solved with the objects to print.
2. The teachers' role. They will be in charge of proposing activities to encourage the pupils while also favouring their autonomy, whereas at the same time they have to combine them with the need to analyse whether the presented designs fit the objectives and whether they will be viable. Nonetheless, a marge of error must be considered for the pupils to realise the mistake on the design once printed.
3. Activities typology. The experts suggest putting into practice different kind of activities linked to the established objective. Basically, there can be activities like contests, where pupils more than struggling for being the first ones will want to design objects to be chosen by their classmates and thus finally printed and given as a present to the school. Another possibility could be that printing is part of a bigger project of robotics. The usefulness of 3D printing for working jointly with other disciplines, for instance, mathematics when making visualisations or calculations of geometrical figures, must be checked.
4. Individual or collective work. It is recommended for the pupils to start working alone in the first stages of getting familiar with the software. Later, when the need has to be resolved and the tasks progress and become more complex the work can be done in pairs, even in more

global projects it is recommended to use groups of 4 or 5 people so that the ideas and abilities can be shared.

Considerations for its implementation

3D printer is a delicate and expensive device: Its maintenance should not rest on the pupils even though it could be supervised by the teachers. The goal of the activities with 3D printers is that pupils observe the global process taken until its use more than to explain to them its 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 its use can rest in subjects closer to engineering and technology, other subjects could make use of it for their own activities.

Finally, with regard to more technical aspects, several precautions must be followed, like using the suitable plastic for each kind of printer and avoid blows or brusque movements which will cause an unbalance in printing.

Resources

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

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

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 more relevant the need for the pupils to experiment first hand its properties and to be given the opportunity to build their own models.***

Objectives

Even though light is the energy manifestation which most allows the obtaining of information about our surroundings, the majority of the population has wrong ideas about its nature. This fact is not surprising as light is a complex phenomenon difficult to understand because its physical parameters are far from human perception. And even according to experts it has been incorrectly taught at schools.

For this reason, the main objective of carrying out experiences in optics and photonics is improving the understanding of what light is and what its properties are. That means that pupils should acquire a global model about light as a wavy and corpuscular phenomenon to be able to explain its interaction with matter both at micro and macroscopic level. Therefore the first task should be to clarify previous concepts the pupils may have, like for instance reflection, refraction, absorption, dispersion, diffraction or photon.

The intention is that pupils can explain daily phenomena and can ascertain what light model they have to apply (geometric, wavy, quantic) according to the event they are analysing. In this way, many intuitive -and possibly wrong- ideas the pupils have will be able to be corrected.

The complexity surrounding the phenomenon of light makes more relevant the need for the pupils to experiment first hand its properties and to be given the opportunity to build their own models.

Pieces of advice for its use in the classroom

The contents about Optics to be included at each educational stage depend on the cognitive level of each age. For instance at the early stages of Secondary school concepts linked to light as an energy source (emission, reflection, refraction, absorption, and detection) and colour can be worked on, whereas on the last stages of Secondary concepts regarding light as a wavy phenomenon and geometrical and quantum optics can be introduced.

The experts recommend:

1. Conduct small researches on the phenomenon to be studied. According to the educational level, these can be simple like for instance, what differences there are among the pupils' glasses or what shape the cars' side mirrors have and why. Other experiences could be based on virtual labs and simulators (to work for instance on light sources types, rays diagrams, refraction and reflection laws, the mechanisms of vision or polarised light). These experiences must have as a starting point the students' daily phenomena. It is the way pupils can better grasp these concepts.
2. Be very careful with language. Since very often the pupils' previous ideas differ from those of the scientific vision their explanation can have language errors hindering learning. In this

sense, the experts recommend not to take for understood certain concepts which despite being quotidian could not be known by the students, like for instance that light spreads in a straight line

3. Make diagrams and drawings. It is a good way to help the pupils to modelling light properties, especially regarding geometrical optics. Optics can be many times be represented by lines, for instance, beams trajectory, mirrors or the angles of optical laws. In this way, they can better remember and understand concepts. Diagrams and drawings can also be of use for the teachers to see the previous ideas of the pupils
4. Work in groups. It is advisable to organise small workgroups, in this way pupils can share ideas, debate and help themselves when carrying out their researches.

Considerations before its implementation

Since optics and photonics allow physics to be related to other disciplines like mathematics (STEAM) and give the pupils a way of work similar to that of the scientists, the experts agree that the teachers must have a strong will for implementing experimentation in these fields already present from Primary school.

It is recommended to start with very elemental practices, like for instance, the pupils by themselves deduce the reflection law by playing with mirrors to guide a light beam, just to consolidate these key concepts which could not be well understood. In general, these practices do not require great technical investments and even a few can be done with virtual simulators.

Also, it should be remembered that experiments by themselves will not allow the pupils to understand science: they should be allowed to suggest researches and go beyond than simple repetition of the teachers' given protocols or the execution of a list of activities.

Resources

Costa MFM (2008), “Hands-on Science”, Selected Papers on Hands-on Science (ISBN 978-989-95336- 2-2); Costa MF, Dorrío BV, Michaelides P and Divjak S (Eds.); Associação Hands-on Science Network, Portugal; pp. 1-13

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: 415-428.

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

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

Practical examples

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

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

Optics: Light, Color, and their uses Educator Guide
[https://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Optics.Guide.html]
(published by the NASA, it is a guide with different experiences around optics and light ordered according to the pupils' age)

NANOTECHNOLOGY

> ***[Nanotechnology] facilitates the generation of debates about the risks and ethical aspects associated to the scientific practice, thus stimulating the critical spirit of pupils.***

Objectives

The existing evidence about the application of nanotechnology in the classroom states that:

- It is a good model for applying STEAM since it favours breaking barriers among the different spheres of knowledge and forces the teams to work in a multidisciplinary way where the researchers have to improve and learn from other fields
- It allows the pupils to be in touch with recent scientific and technical discoveries and how they are present in their everyday life
- It facilitates the generation of debates about the risks and ethical aspects associated to the scientific practice, thus stimulating the critical spirit of pupils
- Pupils are in contact with a more authentic way of doing and communicating science

Pieces of advice for its use in the classroom

The consulted experts agree that the implementation of nanotechnology should consider the following issues:

1. Accompany it with the maximum of practical activities. Nowadays in a few teachers' resources centres, there are kits with material for schools which also allow to carry out low-cost experiments (with dice, effervescent pills)
2. Use nanotechnology for explaining common science. For instance, for working on magnetism it is recommended to make use of the ferrofluid properties, for working on optical properties use gold without the expected colour, or to talk about biology or chemistry link the biocide capacity of silver.
3. Start with daily problems or situations. Inquiry about what the state of the art is in a particular case and find how nanotechnology might help and thus make it easier the interaction of the pupil with its environment. For instance in the treatment of a determined kind of cancer.
4. Take advantage of the net resources, be them didactical videos or about augmented reality which facilitate the pupils to understand and visualise the world of nanotechnology.
5. Complete classroom activities with visits to research centres and laboratories

Considerations before its implementation

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

It is also recommendable to strengthen pupils' work in small groups, between 4 and 6 people, and ask for a final product in the shape of a video or scientific poster where they have to put into practice their skills on digital tools, communication and synthesis.

Last, 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 [http://statnano.com/] (indicators and statistics about nanotechnology development on a global level)

National Nanotechnology Initiative [http://nano.gov/] (Educational material and other initiatives related to nanotechnology from the USA government)

Nanopinion [http://nanopinion.archiv.zsi.at/en/education.html] (Website with examples from activities to videos about nanotechnology or teachers' training)

Practical examples

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

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

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