sySTEAM

systematic approach for implementation of STEAM education in schools

GUIDELINES FOR ADOPTING TECHNOLOGIES IN SCHOOL

Authors: David Segarra, Belén López, Laura Rubio, Rafael Marín (FCRi). With the collaboration of Antoni Chaquet López, Joan Fonollosa, Álex Ortiz, Eduard Margelí, Víctor López, Marcel Costa, Víctor Grau, Silvia Zurita, Jordi Díaz-Marcos.

Funded by the Erasmus+ Programme of the European Union

Contents

Funded by the Erasmus+ Programme of the European Union

INTRODUCTION

The so-called STEAM disciplines (science, technology, engineering, art and mathematics) offer a unique opportunity for involving pupils in processes analogous to those in science: inquiry, experimentation, modelling, argumentation … Participation in all these research practices helps pupils to understand how scientific knowledge is generated, making a holistic approach necessary for effective science and technology education.

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

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

Funded by the Erasmus+ Programme of the European Union

General directions: using STEAM projects in the classroom

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

Teaching recommendations:

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

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

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

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

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

Funded by the Erasmus+ Programme of the European Union

The content of this publication does not reflect the official opinion of the Education Exchange Support Foundation, the European Union or its institutions. Responsibility for the information and views expressed in the publication lies entirely with the author(s).

Inquiry-based teaching

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

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

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

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

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

Basic considerations about IBSE:

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

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

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

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

Funded by the Erasmus+ Programme of the European Union

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

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

Funded by the Erasmus+ Programme of the European Union

PROGRAMMING

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

Objectives

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

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

Tips for using programming in the classroom

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

- **Separate digital language from the science to be learnt**. Students must acquire some basic programming skills before applying them to new learning material. Teachers can start by asking pupils to programme video games or animations where different characters interact, which will motivate them while simultaneously familiarising them with the functioning of the software.
- **Be incremental**. If students are supposed to programme a certain model of any natural phenomenon, then they should start with simple processes, for instance, the warming of a glass of water in the sunlight. Henceforth, other more complex processes can be modelled, like the distribution of power from a Van der Graaf generator. Likewise, if an activity aims to teach students how different programming languages function, they should start with simple tasks that do not imply many orders, so that the pupils can get comfortable with them step by step.
- **Use cross-cutting tools**. Programming cannot be an exclusive domain of technology or engineering. It must be cross-disciplinary, touching all subjects. Educational centres should be organised so that pupils can learn programming in any discipline.
- **Use the tool to promote diverse approaches**. Programming allows each pupil to work independently, meaning that everybody can learn and work at their own pace. That's why it is important to establish clear objectives when planning activities, bearing in mind that pupils will always have to start by outlining their model on paper. For instance, when programming a game, it is vital that rules are clear from the start; for an animation, programmers must sketch an outline; and when explaining a natural phenomenon, it is necessary to know what factors play a role.

Funded by the Erasmus+ Programme of the European Union

Considerations before implementation

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

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

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

Resources

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

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

Scratch for Educators: on the page for teachers, there are tutorials, guidelines and opportunities to work online with students (https://scratch.mit.edu/educators/)

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

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

Practical examples

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

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

Funded by the Erasmus+ Programme of the European Union

ROBOTICS

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

Objectives

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

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

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

Tips for using robotics in the classroom

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

- **Make activities progressively difficult**. Although the objective of robotics is to build an object that all students have to conceive in order to solve a real-life problem, they will need a foundation of skills, especially in the field of programming. Experts recommend carrying out small previous exercises, with very simple guidelines, so that pupils perceive the correlation between programming and robotics and acquire the knowledge they will need to build their device.
- **Organise working groups**. Successful progress in robotics projects largely depends on teachers' ability to organise their pupils in balanced groups with different abilities and skills. If this step is achieved, students will find it easier to perform a single task, such as coordinating the group's work, explaining the project to classmates, or applying maths skills or spatial vision. Groups can also integrate pupils' diverse strengths. The maximum recommended number of pupils is 4.
- **Require final products**. Besides the robot itself, project-based activities should be accompanied by a project report, detailing the technological process; an oral presentation in front of the rest of the group (as in a science fair or a sales pitch for a prototype); and a video showing the functioning of the robotic device (this is ideal in case something fails and does not work properly during the live presentation).
- **Assess all facets of the project**. In addition to grading the final product of a robotics project (whether or not the robot works), other items should also be assessed, including group coordination and individual participation. Likewise, pupils should have the opportunity to assess the other projects, even voting for the best one.

Funded by the Erasmus+ Programme of the European Union

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

Considerations before implementation

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

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

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

Resources

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

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

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

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

Practical examples

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

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

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

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

Funded by the Erasmus+ Programme of the European Union

VIRTUAL AND REMOTE LABS

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

Objectives

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

- To facilitate experiments and practicals that cannot normally be carried out in the educational centres' labs owing to lack of equipment.
- To carry out experiments without any risks, thus reducing pupils' aversion to making mistakes.
- To help illustrate phenomena or structures that are difficult to represent with traditional methods like blackboards.
- Offline labs cannot be completely replaced by online ones; rather, the two tools are complementary. Besides, students may resent the overuse of electronic devices (PCs, laptops, tablets).

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

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

Tips for using virtual and remote labs in the classroom

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

- **Plan simple activities with clear objectives**. Pupils will achieve the best results from using these technologies if activities are straightforward and the goals are clear. This means that although pupils can work independently, guidelines and instructions must be easy to understand so that students' curiosity can be freely explored, and so they can learn the need for systematising research.
- **Monitor activities**. Teachers play a guidance role during the activities even if experts recommend not controlling the entire process. Teachers should pause the activity from time to time to share issues and discuss pupils' progress. Otherwise pupils may simply play with the simulations without using them properly.

Funded by the Erasmus+ Programme of the European Union

- **Generate results**. It is necessary to create a final product, which could be a report on the practical or a question worksheet on the part of the scientific process that the class is working on. For instance, pupils might answer a few initial questions, make a hypothesis or write the conclusions of the experiment.
- **Use the technology properly**. Virtual and remote labs should be used only when they are really necessary, for instance, to simulate an experiment that cannot be carried out at the school due to lack of appropriate resources. Simulations should complement real experiments, not replace them.

Considerations before implementation

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

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

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

Resources

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

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

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

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

Vozniuk, A. (2017). Enhancing social media platforms for educational and humanitarian knowledge sharing: analytics, privacy, discovery, and delivery aspects. [pdf] Lausanne (Switzerland): École Polytechnique Fédérale de Lausanne.

Practical examples

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

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

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

Funded by the Erasmus+ Programme of the European Union

EDUCATIONAL VIDEO GAMES

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

Objectives

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

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

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

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

Tips for using educational videogames in the classroom

- **Consider at what point in the didactic sequence to introduce the video game**. The great variety of existing video games makes it possible for teachers to use different types for working different aspects of the scientific context. So, the teacher's task is to correctly sequence the use of the video game to make it a meaningful part of the learning process, whether it is used in the moment of inquiry, the framing, or in the application of knowledge.
- **Ensure a simple initiation**. All pupils will have to be able to master at least some of the video game, and henceforth the teacher will have to facilitate progress through more complex stages. There are video games allowing gamers to advance through different levels as they acquire the skills for solving more complex models or finding more elaborate answers and explanations.
- **Combine online and offline activities**. Evidence in didactics research shows that students learn less when using only online technologies or digital tools than when they combine on- and offline activities, like paper and pencil activities or hands-on practical experiments.

Funded by the Erasmus+ Programme of the European Union

Considerations before implementation

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

- **Use of rewards**. Although the objective of the video game is competitive, rewards cannot be linked to a traditional teaching paradigm. Strategies recreating the conditions of people doing research could be developed. For instance, as the game advances, participants could win points towards obtaining materials for use in the school lab practicals.
- **Elaborate solutions**. Players should not be able to win the video game using a simple Internet search, but by giving complex answers that lead to other questions.
- **Not focusing on purism**. Pupils should be able to advance in the video game without having to use specific language or knowledge. It is more important that students be able to structure and relate concepts than to know a certain vocabulary.

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

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

Resources

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

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

Dragon Box: portal with different computer and mobile applications of online games that can be downloaded, for a fee (https://dragonbox.com/)

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

Practical examples

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

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

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

Funded by the Erasmus+ Programme of the European Union

LOW-COST EXPERIMENTATION

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

Objectives

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

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

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

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

Tips for using low-cost experimentation in the classroom

- **Get motivated**. Teachers must be motivated to conduct these experiments without fear of malfunctions. This can be promoted through previous training to learn new experiments. Online resources on low-cost experimentation can also be consulted.
- **Ration their use**. Sometimes, students continually ask to do experiments, but teachers should only use them to achieve pre-defined learning objectives.
- **Design clear activities**. For pupils to become familiar with practicing the scientific method, activities should be designed in a very clear way to work different concepts, like hypothesis, conclusions, validation, etc.
- **Seek flexible spaces**. Although there are no big technical requirements to conduct these experiments, classrooms should have the flexibility to adapt the space to the needs of the experiment (tables and chairs not fixed on the floor). A few experiments can even be done outdoors.

Funded by the Erasmus+ Programme of the European Union

The content of this publication does not reflect the official opinion of the Education Exchange Support Foundation, the European Union or its institutions. Responsibility for the information and views expressed in the publication lies entirely with the author(s).

Considerations for implementation

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

- **Do a trial run**. Experts recommend teachers test the experiment before carrying it out in the classroom with the pupils.
- **Use them frequently**. This kind of experiment should be done regularly so that pupils develop the necessary habits and understand the norms that will eventually allow them to work independently. Students should work in small groups of 2 to 4 people.
- **Design a suitable sequence for the activity**. Low-cost experiments should not simply replicate protocols previously facilitated by the teachers; instead they have to allow students to reflect on how to carry out a certain demonstration, thus facilitating meaningful learning.
- **Produce results**. It is important that students produce a digital or hard-copy record, where they can think about the experiment and avoid understanding it as a simple game. Any number of final products can be produced: from an assignment with closed questions to a lab notebook where all the experimental steps are written.
- **Perform a final assessment**. The final assessment should serve two purposes: first, it should evaluate the pupil's interpretation and academic progress, and second, it should examine whether the experiment works. Experts recommend asking the pupils to assess the experiments conducted during the academic course. In this way, teachers can obtain very valuable feedback, letting them know whether certain aspects or their approach to the experiment should be rectified.

Resources

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

Practical examples

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

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

Funded by the Erasmus+ Programme of the European Union

3D PRINTING

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

Objectives

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

- answer a certain need, including one proposed by the teacher (for example, to create a decorative object for the room, compete in a contest for designing objects related to the school, or obtain pieces for building a robot or another electronic device);
- test the viability of their designs, because often the pupils tend to design objects that 3D printers cannot print. By trying it out, they will be learn how technical limitations affect engineering or research projects;
- learn to make models, as they will have to express their ideas and make drawings with the support of suitable software.

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

Tips for using 3D printing in the classroom

- **Familiarise students with the design software**. Pupils should start at the early stages of secondary school to familiarise themselves with the use of software for designing things to be printed, like Scratch. Curricular continuity should ensure that as pupils move forward in the courses, their needs be met with printable objects.
- **Play a guiding role**. Teachers will be in charge of proposing activities to encourage pupils while also favouring their independence, while at the same time analysing whether the presented designs are viable and fit the lesson objectives. Some margin for error must be allowed for pupils to realise their mistakes on the design once printed.
- **Diversify activities**. Experts suggest putting into practice different kinds of activities linked to the established objective. There can be activities like contests, where the winners are chosen by their classmates based on their design and get to print out the object to be given as a present to the school. Another possibility could be making printing part of a larger robotics project. The usefulness of 3D printing for working jointly with other disciplines, for instance mathematics when visualising or calculating geometrical figures, can be explored.
- **Use both individual and collective work**. Pupils should start working alone in the first stages, to get familiar with the software. Later, task-based activities and more complex work can be done in pairs, and for even larger projects, groups of 4 or 5 people are better so that pupils can share ideas and abilities.

Funded by the Erasmus+ Programme of the European Union

Considerations for implementation

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

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

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

Resources

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

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

Practical examples

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

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

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

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

Funded by the Erasmus+ Programme of the European Union

The content of this publication does not reflect the official opinion of the Education Exchange Support Foundation, the European Union or its institutions. Responsibility for the information and views expressed in the publication lies entirely with the author(s).

OPTICS AND PHOTONICS

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

Objectives

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

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

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

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

Tips for using optics and photonics in the classroom

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

- **Conduct small research projects on the phenomenon to be studied**. According to the educational level, these can be as simple as examining the differences between pupils' glasses or analysing the shape of cars' side mirrors. More complex experiments could be based on virtual labs and simulators (for instance, to work on the types of light sources, ray diagrams, refraction and reflection laws, the mechanisms of vision and polarised light). These experiments must draw from the daily phenomena in students' lives so that they can better grasp the concepts at hand.
- **Be very careful with language**. Since pupils' previous ideas often differ from a scientific vision, their explanations can contain language errors hindering learning. In this sense, experts recommend not assuming that students understand certain concepts; even if these seem like basic, everyday concepts, students may not understand them, for instance the fact that light travels in a straight line.

Funded by the Erasmus+ Programme of the European Union

- **Make diagrams and drawings**. This is a good way to help pupils model the properties of light, especially geometrical optics. Optics can often be represented by lines, for instance to show the trajectory of beams, mirrors or the angles of optical laws. This representation can help students remember and understand concepts better. Diagrams and drawings can also be of use for the teachers to see students' pre-exiting conceptions.
- **Work in groups.** It is advisable to organise small work groups so pupils can share ideas, debate and help themselves when carrying out their research projects.

Considerations before implementation

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

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

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

Resources

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

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

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

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

Practical examples

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

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

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

Funded by the Erasmus+ Programme of the European Union

NANOTECHNOLOGY

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

Objectives

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

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

Tips for using nanotechnology in the classroom

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

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

Considerations before implementation

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

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

Funded by the Erasmus+ Programme of the European Union

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

Resources

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

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

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

Practical examples

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

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

Funded by the Erasmus+ Programme of the European Union