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CASOS INTERDISCIPLINARES Y MULTIDISCIPLINARES PARA UN APRENDIZAJE STEAM CONTEXTUALIZADO

INTERDISCIPLINARY AND MULTIDISCIPLINARY CASES FOR CONTEXTUALIZED STEAM LEARNING

Gabriel Pinto Cañón

Doctor in Chemical Sciences from the Complutense University of Madrid, he is a Professor of University (in the field of Chemical Engineering) at the Polytechnic University of Madrid and president of the Specialized Group in Didactics and History of Physics and Chemistry, shared by the Royal Spanish Societies of Physics and Chemistry.

Resumen

Se resumen algunos trabajos desarrollados en las últimas décadas, con idea de favorecer un aprendizaje activo sobre temas STEM y STEAM. Se trata de problemas, cuestiones, experiencias prácticas, y ejercicios específicos sobre conceptos de ciencias (principalmente física y química) con implicaciones de historia y arte, diseñados e implementados para alumnos de primer curso de ingenierías y de Máster de Formación del Profesorado. Además, se han difundido en ferias científicas y cursos de actualización del profesorado, con idea de

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poderlos utilizar en las diferentes etapas educativas. Dada la peculiaridad y su carácter inter y multidisciplinar, se considera que el conocimiento de estas herramientas educativas puede ser de especial utilidad, tanto para profesores (propuestas de aplicación concreta de 'situaciones de aprendizaje' en ESO y bachillerato) como para inspectores de educación.

Palabras clave: *aprendizaje activo, educación STEM y STEAM, interdisciplinariedad, multidisciplinariedad, situación de aprendizaje.*

Abstract

This paper summarizes some of the works developed in recent decades, with the idea of promoting active learning on STEM and STEAM subjects. These are problems, cases, questions, practical experiences and relations between science (mainly chemistry) and aspects of history and art, designed and implemented for first-year engineering students and others studying for the Master's Degree in Teacher Training. They have also been disseminated at science fairs and teacher refresher courses, with the idea of being able to use them at different educational stages. Given their peculiarity and their interdisciplinary and multidisciplinary nature, it is considered that the knowledge of these educative tools can be especially useful, both for teachers (proposals for the specific application of 'learning situations' in ESO and baccalaureate) and for education inspectors.

Keywords: active learning, interdisciplinary, learning situation, multidisciplinary, STEAM and STEAM education.

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1. Introduction

In recent years, there have been a series of transformations in the methods and techniques for the teaching and learning process, at all educational stages, which can be described as vertiginous. These transformations have taken place worldwide, motivated by the increasing importance given to education for the development of countries, and by the relevance achieved in modern society by information and communication technologies. Suffice it to consider, as an example, the irruption, in recent months, of artificial intelligence tools such as ChatGPT. In many ways, these transformations have been accelerated by the recent pandemic caused by COVID-19, which was a "litmus test" for the continuity of educational tasks.

Spain has not been oblivious to these changes, which are promoted as the implementation of successive legislative reforms in all educational fields. The implementation of educational innovation is also encouraged through discussion and the contribution of evidence, by teachers, through articles in specialized journals, books, seminars, courses, etc.

In current compulsory secondary education and baccalaureate, some essential aspects in this regard are, among others, the competency-based training approach, new assessment criteria and the design of 'learning situations' (scenarios and activities that involve the deployment by students of actions associated with competencies and that contribute to the acquisition and development of these competencies).

Additionally, the field or set of STEM competencies (Bybee, 2010; Pinto, 2022a), an acronym for Science, Technology, Engineering and Mathematics, has been progressively introduced (Bybee, 2010; Pinto, 2022a). Originating in the United States a little more than three decades ago, to promote these disciplines and encourage vocations, the term STEM has been applied to education in response to concerns about poorly integrated teaching and the lack of

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knowledge of these fields at an early age. STEAM terminology is also used, including the "A" in Arts, to foster creativity and enhance other skills (Liao, 2016; Radziwill, Benton, & Moellers, 2015). Somehow, it seems that STEM or STEAM education promotes integrated teaching and learning, promotes approaches to technological problem solving, is some guarantee of transversality, facilitates contextualized learning, and redounds to giving the teacher the role of guide and mentor. Like almost everything in education, it is not free of controversy; some authors argue that "STEM education" can be a new distraction for science teaching (García Carmona, 2020) and others, such as Quílez (2022), raise the problems derived from its lack of precise conceptualization, among other aspects.

The Spanish University has also taken important steps towards its transformation in terms of pedagogical approaches in the last two decades, as part of the global process with which it has collaborated in the construction of the European Higher Education Area (Pinto, 2010). Some of the significant steps have been the new degree structure (Bachelor, Master and Doctorate), the perspective of education based on the acquisition of competences (transversal and specific), the importance given to the role of the student as an active agent and protagonist of his learning, the introduction of new forms of evaluation, the use of innovative methodologies (problem-based or case-based learning, gamification, inverted classroom, cooperative work, service-learning, etc.), etc. As a result of this university context, and in relation to what has been addressed in this paper, it is important to highlight the beginning of the teaching of official Master's degrees that enable the professional practice of the professions of Teacher of Secondary Education and Baccalaureate, Vocational Training and Language Teaching, since its regulation in 2007 by Royal Decree 1393/2007.

According to the Royal Spanish Academy, the adjective "multidisciplinary" refers to "encompassing or affecting several disciplines", while "interdisciplinary" or "interdisciplinary" is "said of a study or other activity: That it is carried out with

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the cooperation of several disciplines". Although the differences between multi- and interdisciplinary are not categorical, it can be argued that, at the level of work organization, while in the first case the objectives of each are addressed from its own perspective, in the second case, common objectives are addressed from different perspectives. In some ways, collaboration and integration between the parties are more intense in interdisciplinary work and teams than in multidisciplinary ones, as these tasks are carried out separately.

In this perspective, the purpose of this paper is to show some examples of how varied learning situations can be proposed, with specific cases contextualized in the students' reality, in an inter or multidisciplinary way, that promote learning in STEAM environments at different educational stages. Among the proposals developed, the following stand out: (a) contextualized problems, (b) questions (analogous to problems but with less quantitative treatments), (c) experimental studies, and (d) proposals for topics that relate science, history, art, and society. Due to space constraints, most of the proposals are summarized, but four specific cases are explained in greater detail as examples of potential approaches. Finally, some conclusions derived from the use of these educational strategies are outlined.

2. Examples of perspectives for contextualized STEAM learning

Searching for active methodologies for students, the author of this work has been developing educational resources for nearly four decades, which he has been completing and updating through teaching practice. What he initially proposed as cases to show the usefulness and applied nature of chemistry for first-year university engineering students, evolved and was successively accommodated to examples of "science and everyday life", training in competences, STEM approaches, at the time, "learning in times of confinement" (Pinto, 2020) and, more recently, "learning situations". But these are not only

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examples intended only for engineering students; apart from applying them and assessing their effectiveness with them, in the last twenty years he has disseminated many of these cases in science outreach activities for all audiences and, especially, in teacher training courses at different educational stages, including the aforementioned Master's Degree in Teacher Training, specializing in Physics and Chemistry. Through interactions with practicing and aspiring educators, the author has witnessed how some of these resources have been implemented (with the appropriate approaches) in the educational stages preceding university.

The resources are based on problem-based learning (PBL), case-based learning (CBL), research, and guided inquiry, primarily in the fields of physics and chemistry. A significant portion of them has been developed in collaboration with secondary school teachers and professors from other universities. Both collaboration and dissemination efforts have taken place not only at the national level but also internationally, allowing for the observation that, despite notable differences in infrastructure, models, etc., the educational issues (student passivity, the need for teacher coordination and professional development, utilization of ICT, etc.) are largely similar across different countries. The objectives of the designed resources are... (Please provide the continuation of the sentence for a more literal translation):

• Boost the learning process to facilitate the understanding of concepts.

• Promote motivation, both of students, when carrying out the activity, and of teachers (when devising, implementing, and evaluating activities of this type).

• Contribute to citizenship training, through CTSA (science, technology, society, and environment) approaches and the promotion of social responsibility.

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• Facilitate training in generic and transversal competencies, such as: STEM and STEAM learning, problem solving, experimentation, data search and analysis, teamwork, preparation of documents and reports, learning to learn, etc.

• Advance in the development of both multidisciplinary and, especially, interdisciplinary educational activities.

• Encourage critical thinking and inquiry on the part of students.

• Offer ideas that can serve as inspiration for other colleagues, to face new cases and topics according to the contents and competences of different subjects, and to design specific learning situations.

These cases have been presented in more detail in previous publications, so the corresponding bibliography is included at the end of this article. It is considered that these contributions may be of particular interest to teachers who wish to know some examples of learning situations for STEM or STEAM education. But also, it is considered that their knowledge can be positive for educational inspectors. As is well known, the main functions of educational inspection, regulated by Organic Law 3/2020, of December 29, which modified Organic Law 2/2006, of May 3, 2006, are as follows:

• Supervise, evaluate, and observe the operation of the centers in organizational and pedagogical aspects (including new educational methodologies).

• Supervise the teaching practice, which has to be oriented towards training by competencies, development of learning situations, etc.

• Collaborate in the evaluation of the educational system, for which it is convenient to have a wide knowledge of the reality to be evaluated.

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• Ensure compliance with the legislation affecting the educational system, which includes the use of varied methodologies.

For the fulfillment of these functions, it will always be positive to know wide perspectives of teaching tools, such as the cases exposed here.

In a significant number of the designed proposals, teamwork is encouraged, and the initial data must be sought (or determined experimentally) by the students themselves and, normally, there is no single valid result. The method of implementation can be varied, from collaborative work in the classroom to its development as a homework assignment. Some of the tools summarized here are considered examples of "consumer science", as they address practical issues in the analysis of commercial product advertisements and labeling. In both these cases and others, the work goes beyond highlighting the relevance of science in everyday activities; efforts have been made to quantify and delve deeper into the analysis of the problems and cases presented.

3. Contextualized problems

In Table 1, some cases are presented as problem-solving exercises for students, following different methodologies, which can serve as the basis for the well-known Problem-Based Learning (PBL) approach (Pinto, 2014). One of the studies involved a detailed analysis of the chemistry involved in water purification, a topic of great interest in contemporary society. Various chlorine compounds (including the element itself) are used as disinfectants, for example, in water treatment for swimming pools and for sanitizing baby utensils like bottles. In addition to the applications, the discussion includes the balancing of redox reactions and the assignment of oxidation numbers, which are fundamental aspects of chemistry (Pinto and Rohrig, 2003). This case provides an example of the need for teachers to have a wide range of resources. The topic discussed has

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been highly relevant during the recent COVID-19 pandemic, as disinfection of objects was one of the methods employed.

Table 1. Developed and validated problems for contextualized multi and interdisciplinary learning in the STEAM fields. References are included in the text.

Problem	**Aspects studied and characteristics**
Chlorine compounds for water disinfection.	Water disinfection and potabilization, calculation of formal charges and oxidation numbers, resonance, chlorine compounds, chemical reactions, consumer chemistry.
Drug labeling information.	Stoichiometric calculations, formulation, chemistry and health, consumer information, pharmaceuticals, calcium compounds, iron salts, biology, numerical approximations.
Stoichiometry of fertilizers.	Importance and composition of fertilizers, stoichiometry, formulation, commercial product information, agriculture.
Composition of mineral waters from the information provided by the manufacturer.	Composition of mineral waters, chemical analysis, thermal decomposition of bicarbonates, scientific information for the public, water hardness, rounding in mathematical operations, types of water, product labeling.
CO_2 emissions and fuel consumption by	Stoichiometric calculations, CO_2 emission, global warming, density of liquids, graphical representations, function fitting, combustion, new engines, simplified

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automobiles.	model development, data mining, sustainability.
Toothpaste and fluoride products for dental care.	Dental care, chemical calculations, formulation, chemistry and health, scientific information for the public, labeling of commercial products, bond distance, isomerism, fluorine compounds, oxidation numbers, formal charges.
CO2 emission reduction using solar cells.	Stoichiometric calculations, CO2 emission, combustion, energy sources, units of measurement, photovoltaic cell applications, greenhouse effect, sustainable development.
Thermochemistry of domestic condensing boilers.	Thermodynamics, heat of combustion, condensation, energy conservation, natural gas procurement, data mining, CTSA (Science-Technology-Society-Environment) relationships, alternative student ideas, consumer science and technology, contemporary history.
Problem solving.	Methodology for problem solving in science, mathematics, contextualization in contemporary life.

Another case is the inquiry into the fact that automobile manufacturers must include, in the information they provide to consumers, data on fuel consumption and the corresponding carbon dioxide emissions. The relationship between these two parameters, which manufacturers obtain experimentally, is not obvious. In this sense, starting from data of this type, the students are asked to represent these values and the chemical justification of the relationship found. The

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procedure should be carried out separately for gasoline and diesel cars. In both types of automobiles, the relationship found between carbon dioxide emission and fuel consumption is of a linear type, as shown in the example in Figure 1. Simplifying the problem, considering that gasoline is essentially made up of octanes, the combustion reaction can be expressed as: $C_8H_{18} + 12{,}5\ O_2 \rightarrow 8\ CO_2 + 9\ H_2O$.

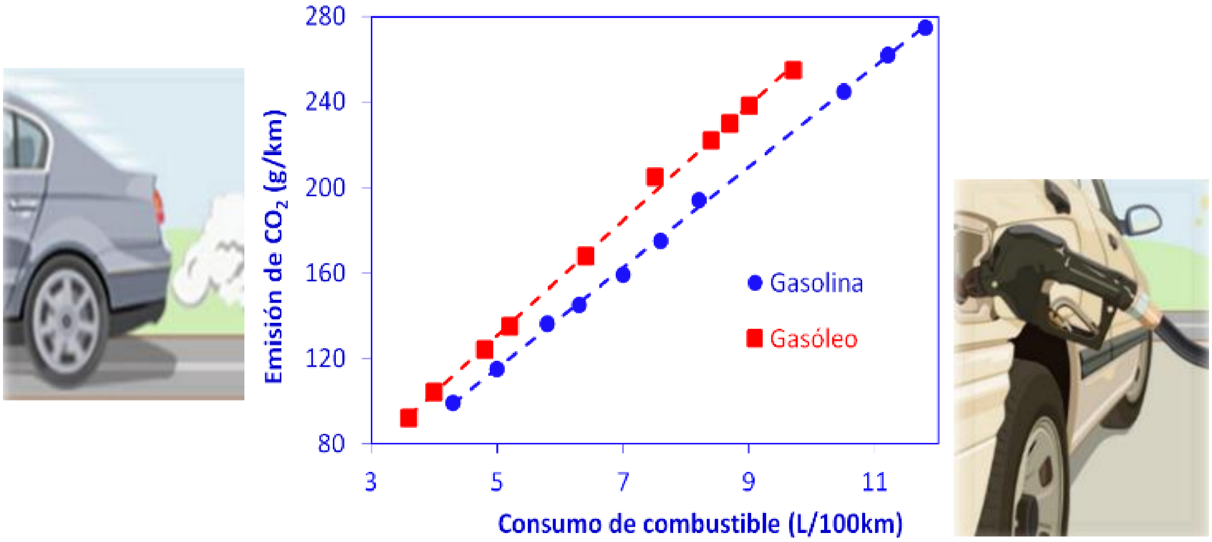

Figure 1. CO2 emissions versus fuel consumption, based on commercial data from automobiles. Created by the author.

Taking a specific value of gasoline density, which students must find, and using the relevant chemical relationships, a linear relationship is obtained, and the calculated values are of the same order as those found experimentally as the slope of the line. CO2 emissions can be compared between diesel and gasoline cars, and students can calculate, for example, the emission of this compound caused by their car journeys, raising awareness of the importance of this aspect in mitigating global warming (Pinto and Oliver-Hoyo, 2008a). This example is

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considered paradigmatic of what is intended with this type of initiative: students perceive how basic scientific concepts allow them to analyze and understand aspects that are often part of everyday life and of great practical interest. Additionally, they need to apply knowledge from various subjects (in this case, Chemistry, Physics, and Mathematics) to solve problems with significant environmental and sustainability implications.

Another case developed is the use of information on condensing boilers for domestic use. Questions are proposed for students to inquire about aspects related to these boilers that produce liquid water in the combustion of the fuel, instead of steam. The objectives are to favor the learning of concepts (thermochemistry, combustion reactions, natural gas composition...); to promote motivation towards science; to encourage Science-Technology-Society-Environment approaches; and to collaborate in the formation of competences (inquiry, problem solving, data analysis, teamwork...). It also promotes critical thinking and, again, training in "consumer science", dealing with aspects such as the reasons for public aid for the installation of these boilers and the use of the gas bill as a source of scientific and technological information (Pinto, 2013).

Water condensation, forced in a boiler called a "condensing boiler", generates more heat than a conventional boiler. Through various information on the topic, students, after investigating the composition of the fuel used (often natural gas in Spain) and searching for thermochemical data, should conclude that this type of boiler, promoted and subsidized by authorities, results in fuel savings and, consequently, a reduction in CO_2 emissions of around 10%. The saving of this type of fuel is currently urgent due to the ongoing conflict in Ukraine. An example of the sequence of questions associated with this problem is:

a.- Collect in a table a typical composition of natural gas, expressed in volume percentage and mole fraction, including the formulas of the substances.

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b.- Collect in another table the composition (expressed in mole fraction and mass percentage) of a "typical" natural gas, considering only the two major hydrocarbons to simplify the calculations.

c.- Elaborate a table where the data are collected (consulting appropriate sources) of variation of enthalpy of formation (in kJ/mol) of the two gases of the previous section and of the following substances: CO_2(g), H_2O(g) y H_2O(l),

d.- Calculate the variation of combustion enthalpy (in kJ/mol) of the natural gas "type", at 25°C, supposing that water is obtained as a gas.

e.- Repeat the calculation of the previous section, supposing that the water is obtained as a liquid.

f.- With the data of the two previous sections, determine the amount of natural gas (moles) that would have to be used, in a condensing boiler, for each mole of natural gas that would be used in the other type of boiler, to obtain the same energy.

g.- Comment on the economic and social implications associated with the result of the previous section.

h.- Reason if the water obtained in the condensing boiler is acidic and the repercussions this fact may have.

i.- Consulting a natural gas bill, indicate the energy obtained (kWh) per unit volume (m3) of gas consumed.

j.- Determine, explaining the changes of units, the energy (kJ/mol) that can produce each mole of natural gas in its combustion, from the value of energy per unit volume of the previous section.

k.- Compare the energy of the previous section with the calculated in sections d and e.

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l.- Calculate the mass of carbon dioxide (kg) that will have been released by the gas consumption indicated in the invoice, taking as an example the "type" gas of section b.

m.- Detail the approximations made.

n.- Comment on any aspect considered of interest in relation to sustainability, the environment, the subsidy offered, etc.

Issues related to this case, as they also allow for a decrease in greenhouse gas emissions, are addressed in another example, which involves analyzing the reduction of CO_2 emissions that occurs when solar cells are used as an alternative to the combustion of fossil fuels to obtain energy (Pinto, 2009a).

Other aspects addressed in the problems, as shown in Table 1, refer to studies on the composition of mineral waters (Pinto and Oliver-Hoyo, 2008b), fluoride compounds for dental care (Pinto, 2009b), medicines (Pinto, 2005a; Prolongo *et al.*, 2014) and fertilizers (Pinto, 2003a). In all of them, data indicated on their labeling is analyzed. They are, on the other hand, emblematic examples of well-known substances provided by chemistry for the improvement of living conditions.

4. Questions about contextualized cases

Table 2 contains some examples of issues that promote multi and interdisciplinary learning for STEAM content (Pinto, 2003b). Among other summarized aspects, the treatment of products used as mothproofing is highlighted. Apart from analyzing and collecting experimental data on the physical phenomenon of sublimation, topics such as the impact of chemistry on society and information provided by the manufacturer of various products are addressed (Pinto, 2005b). This example also deals with the study of the biology of

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Lepidoptera, the effect of mothproofing substances on moth larvae, and the damage caused by these substances on textile materials (Pinto, 2005b).

Another original study has been the reasoning on the causes of the effect known as "jumping" of the oil when water is added to hot oil, for example in food cooking, while no effect is observed when the opposite occurs (Pinto and Gauthier, 2009). Aspects such as the different densities and boiling points of these two liquids, as well as their immiscibility, are introduced in the reasoning. Some applications, apart from a better understanding of the properties and structures of fats and oils, are aspects such as how to extinguish an oil fire in the home and the relationship between structure and properties of the substances. Some aspects related to the experience are illustrated in Figure 2.

Other educational proposals developed by the author to favor the dissemination of science are analogies, in which he tries to get students to work on scientific concepts using objects from everyday life, well assimilated by them. For example, an exercise was prepared in which the comparison of the variation of atomic and ionic sizes with the change of sizes of balls of different sports is proposed (see figure 3). It is intended that the visualization of the size variation of well-known objects from different sports will allow understanding the magnitude of the change in atomic volume that occurs between the different elements of the periodic table and their ions (Pinto, 1998). He has also proposed the use of everyday materials, such as polystyrene balls, candy, chestnuts, and sticks, to represent molecules and thereby discuss some properties of substances, such as the transformations and change of behavior of sulfur when heated (see Figure 4) (Pinto, 2018). In this way, certain skills are also fostered among students, such as creativity.

Table 2. Questions developed and validated for contextualized, multi and interdisciplinary learning in STEM domains. References are included in the text.

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Case or question	**Aspects studied and characteristics**
Everyday life experiences and analogies for learning science.	Dissemination of science, examples of analogies (resonance, distinction between formal charges and oxidation numbers...), effectiveness of using cases from everyday life in students' learning.
Mothproof products.	Insecticides, sublimation, lepidopteran biology, labeling, chemistry and health, consumer information.
Effect of water on hot oil.	Density, miscibility, characteristic temperatures (boiling, smoke, and ignition) of oils, crackling, fire precaution in the kitchen, safety, composition of everyday substances.
Cooling of water in ceramic containers.	Enthalpy of vaporization, climatology, Science-Technology-Society implications, cooling of water in porous ceramics, thermodynamics, wet bulb temperature, food preservation, chemical kinetics, characteristics of clays, geography, history.
Analogy between balloons and atoms.	Periodic properties of elements, sizes of atoms, analogies, ionization of atoms, ion packing.
Preparation of smoke of different colors.	Chemical characteristics of smokes for the choice of pope, formation of colors in smoke, substances for pyrotechnics, colored smoke generating devices for lifesaving.
The	Relationships between art, history, science and

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Atomium of Brussels.	society, geometry, crystalline cells, structure of metals, numerical calculation, and creativity.
Applications of osmosis.	Osmotic flow, applications of osmosis (pickled gherkins, fish physiology…), reverse osmosis, seawater desalination.
Molecular geometry.	Relationship between structure and properties of substances, molecular geometry with household objects (fruits, candies, toothpicks…), creativity.
Periodic table and atomic models.	History and meaning of the periodic table. Resources for learning atomic models and periodic properties of chemical elements.

Briefly, other works summarized in Table 2 are: the use of the Brussels Atomium to deal with questions of introduction to crystallography, chemical elements discovered by Spaniards, geometrical calculations, etc. (Pinto, 2012); the preparation of colored smoke for various applications, from the announcement of the election of the Pope of the Catholic Church to the use in maritime and mountain rescue (Pinto and Vieta, 2013); use of postage stamps and other resources to analyze the periodic properties of chemical elements and molecular models (Pinto, 2007; Pinto, Martín and Prolongo, 2020); and the explanation of osmosis (Pinto, 2016), with important implications in cell biology and applications ranging from the preparation of pickled gherkins to the desalination of seawater (Pinto, 2016).

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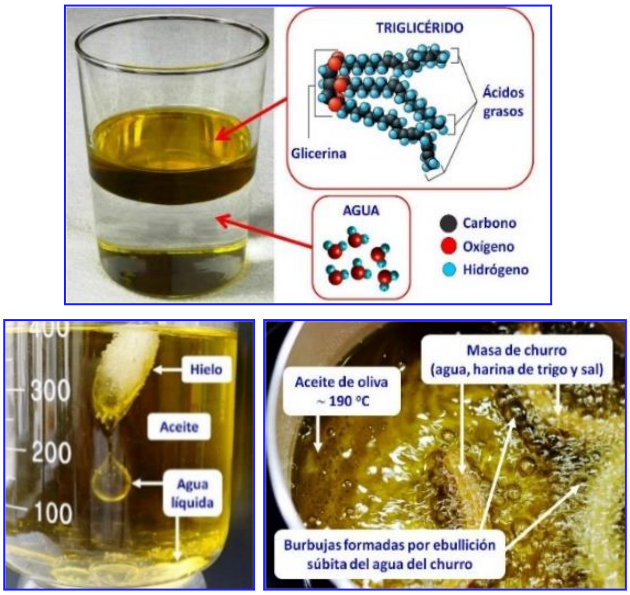

Figure 2. Illustrations of the molecular structure and behavior of cooking oil and water. Own elaboration.

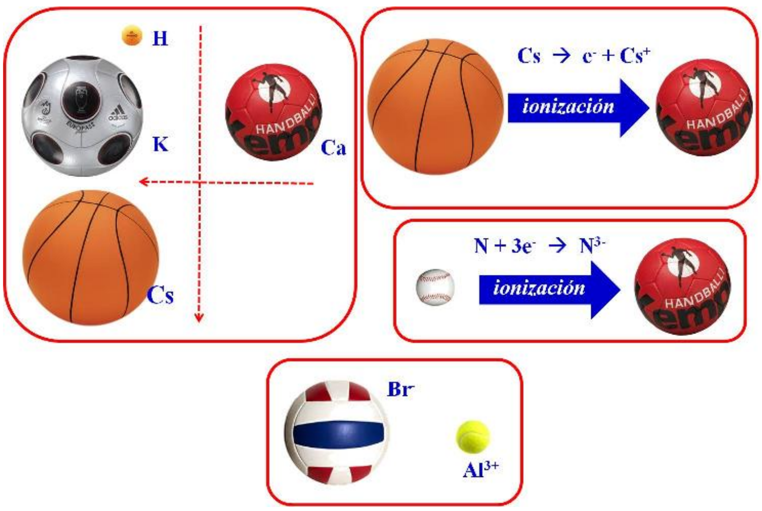

Figure 3. Analogy of atomic and ionic dimensions, made with balls and balls of different sports. Own elaboration.

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An emblematic example cited in Table 2 is the cooling of water contained in porous ceramic vessels (such as the popular *botijos*). The quantitative treatment involves a certain complexity of thermodynamics and mathematics, and exceeds the objectives of this article, but can be adapted to different educational stages (Zubizarreta and Pinto, 1995). Other everyday aspects are presented here, related to the cooling of water that occurs when it is stored in porous ceramic containers. This effect, well known in practice for thousands of years, with the corresponding adaptation, can be used to strengthen key competences and, more importantly, basic competences in science and technology. Apart from favoring the understanding of physicochemical concepts (heat of vaporization, heat transfer, evaporation, air humidity, vapor pressure, etc.), it is a cross-cutting and interdisciplinary topic that allows raising aspects of technology (such as the relationship between structure, properties and processing of clays, or food preservation by refrigeration) and climatology, as well as approaches of the Science-Technology-Society type, and the interpretation of other phenomena (such as the functioning of the scientific toy known as the “drinking bird”), among others (Pinto, Martín and Martín, 2017). Its 'functioning' has been well understood for a long time: due to the porosity of the ceramic, water exudes (by capillarity) which, when evaporating, takes the necessary thermal energy (latent heat of vaporization) from the water inside, causing it to cool down. The lowest temperature to which the air can reach by evaporation of the water inside it or humid temperature of the air will determine the theoretical minimum temperature that the water in a botijo can reach. In addition to the cooling that occurs when the water evaporates, heating is produced by the (warmer) air surrounding the water in the earthenware pitcher.

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Figure 4. Analogy to understand properties derived from the molecular structure, from models made with polyethylene foam and sticks. Own elaboration.

There are other cases that can be applied in the same educational context, such as the ceramic device known as "pot-in-pot", designed by Nigerian professor Mohammed Bah Abba. It works without the need for electricity and, for the inhabitants of certain African villages, it has been a fundamental milestone in their development.

To prepare ceramic objects, such as those shown here, a suitable clay is treated with water, which makes it deformable (it acquires a "plastic" behavior). Clays are made up of various types of silicates and aluminosilicates with a lamellar structure. They become plastic (easily deformable) with water because this substance gives them a 'lubricating' effect that facilitates the displacement of the lamellae among themselves. All this can be analyzed in the Technology course, when dealing with ceramic materials. Once a piece of wet clay has been

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shaped into the desired form, it is subjected to a drying and heating cycle in kilns at the appropriate temperature, producing a series of chemical processes of silicate transformation, which make the material rigid and, therefore, no longer deformable. On the other hand, the decrease in temperature that occurs in the internal vessel of the pot-in-pot causes a slowing down of the biochemical processes of degradation of the food stored there, increasing its shelf life (Pinto, Martín, and Martín, 2017). Broadly speaking, this is the rationale for refrigerating food for longer preservation: the rate of chemical reactions decreases as the temperature decreases. Quantitatively, it is often governed by the Arrhenius equation, which is covered in high school chemistry. The life of bacteria (unicellular living beings) that degrade food is based, like that of any other living being, on chemical reactions that take place inside the cells and, at low temperature, become slower.

What has been discussed in the previous sections can serve as inspiration for teachers of different educational levels and environments to tackle a wide variety of educational tasks (see Figure 5). For example, students can measure the variation over time of the mass of water and the temperature in a water jug as it evaporates, controlling the external variables (mainly temperature and humidity). They can also do the same, to study a pot-in-pot refrigerator built with pots of different diameters, or by preparing the containers themselves from clay. In this case, they can experiment the effectiveness of the refrigeration achieved in the conservation of different types of food and propose proposals for improvement. Apart from making the containers themselves, they can also delve into the meaning of the wet bulb temperature and its measurement (by surrounding the bulb of a thermometer with a cloth dampened in a stream of air), discuss the difference between evaporation and boiling (not easy for students to understand), or reason about what is the vapor pressure of a liquid. Some questions that can be posed to the students are: What would the effects studied be like with liquids other than water? Why don't varnished jars work to cool the

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water? Why does the liquid inside rise and cause a mechanical imbalance in the drinking bird? Why does it stop if it is introduced into a glass bell?

Figure 5. Concepts covered through the educational approach developed on water cooling in porous ceramic vessels. Own elaboration.

5. Cases of contextualized experimental studies

Table 3 includes some examples of experimental proposals that have been presented to promote contextualized STEAM learning.

Regarding the experimental studies summarized in this table, one topic concerns the study of the kinetics of the osmotic hydration process of legumes when they are "soaked" prior to cooking (Pinto and Esín, 2004). In this case, we proceeded with chickpeas, and studied how the mass of these legumes, submerged in water, increases over time. The influence of the concentration of sodium chloride present in the water and of the temperature was analyzed. The

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experimental exercise, which can be done in the kitchen at home, is a useful tool to relate mathematical and graphical calculations with aspects of physics and chemistry (interdisciplinarity is promoted), as well as to introduce concepts such as osmotic flow, mass transfer, diffusion, hydration kinetics, modeling, and estimation of activation energies. In addition, it can be useful to introduce students to the importance of the cellular flow of water in living organisms.

Another proposal was to measure the dissolution rate of effervescent tablets at various temperatures. Apart from discussing effervescence, experimental work is promoted (which students can do at home) leading to the need to make graphical representations and quantitative treatments that require calculating the slope of a straight line (Pinto, 2000). In addition, proposals for contextualized experiences have been carried out related to the reaction of sodium in water (Martín *et al*., 2015a), Tollens' reagent to introduce nanotechnology (Pinto *et al*., 2015), a practical hydrostatics problem to address the “scientific method” (Oliver-Hoyo, Alconchel and Pinto, 2012), special effects in cinematography (Pinto, Prolongo and Alonso, 2017), introduction and use of catalysts (Pinto and Prolongo, 2023), and the use of familiar everyday substances such as hydrogen peroxide, tea (Prolongo and Pinto, 2021) and lollipops (Prolongo and Pinto, 2018) to perform colorful chemical reactions.

Table 3. Experimental proposals developed and validated for contextualized, multi and interdisciplinary learning of STEAM domains.

References are included in the text.

Experience	**Aspects studied and characteristics**
Hydration of legumes.	Measurement, graphs, osmosis, effect of temperature and salt concentration on hydration rate of 'soaked'

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	legumes, food.
Self-heating food containers.	Heat of dissolution, reaction energy, temperature and density measurement, thermal calculations, device design, data mining, active packaging, product labeling, design
Effervescent tablets.	Effervescence, influence of temperature on reaction rate, graphs, activation energy calculation, drugs, health.
Reaction of sodium with water.	Chemical concepts (redox reactions, pH...) and physical concepts (buoyancy, kinetics...), Science-Society relations (analysis of an accident).
Melting speed of ice.	Introduction to the scientific method, experimentation, inquiry, thermohaline ocean currents, climate, convection, density.
Tollens' reagent and nanotechnology.	Historical introduction to Tollens reagent, formation of silver mirrors, aldehyde identification, nanotechnology, history.
A hydrostatic problem.	Inquiry, hydrostatics, experimental problem solving, buoyancy, practice with household objects, history of science.
Cinema: special effects.	Super water-absorbent plastics, special effects (snow, fog, artificial blood, invisible inks and objects...), history, cinematography.
Learning chemical reactions and catalysis.	Chemistry in everyday life, types of reactions, catalysis experiments with everyday materials, simulation with everyday objects (buttons, polystyrene...), automobiles, environment, sustainability.

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Experiments with daily substances.	Chemistry of everyday substances (hydrogen peroxide, tea, lollipops...), redox reactions between permanganate salts and glucose, methods of stirring liquids, science of everyday life, cooking, creativity.

In recent years, it is common that, on the first day of class, to introduce the "scientific method", the author of this work asks the students a question: "Where does a block of ice melt first, in water or in water saturated with salt?" (Pinto and Lahuerta, 2017). They are given a minute to think and then their answers are collected. Afterwards, they are suggested to discuss the question in groups of three to, again, ask for the answer they provide (individually). The answers are usually similar in different years: 70% to 80% think that it melts earlier in saline water, 10% to 20% think that in pure water, and another 10% to 20% are divided between answering that there is not much difference or admitting that they do not know. After the team discussion, the percentage of those who answer the first option usually increases. The students then discuss with the students how the question could be solved and, after an exchange of ideas, it is resolved that it can be done by them, in their own kitchen at home. They are offered a week to solve it, indicating that they can consult with the teacher during that time, any aspect in this regard. After a week, the students who have carried out the experiment at home usually realize, to their surprise, that the result is the opposite of what most of them thought. Afterwards, the students are told that they have three weeks to carry out, in groups of three, the experiment in more detail, as well as to study the influence of some other variable, such as different concentrations of salt, another solute (such as sugar), etc. In addition, they are instructed to write a report on the experiment, justifying the results, which may include details such as photographs or links to videos. Once the reports have been analyzed by the teacher, a discussion is held in the classroom, where apart from commenting on the results

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obtained, a demonstration is carried out where a drop of food coloring is added to the edge of the ice blocks in the two liquids (water and saturated aqueous solution of salt). The result serves to comment that the fundamental cause of the observed phenomenon is the generation of convection currents in the pure water medium, due to the higher density of the liquid water formed when melting the ice, while, in the case of the salt solution, due to its higher density, no such currents are produced. It is a good opportunity to highlight the importance of thermohaline currents in the oceans, caused precisely by the differences in temperature and salt concentration in various aqueous layers, in climate and in the transport of microplastics (Pinto and Martín-Conde, 2023).

Another example of the work presented in Table 3 is the use of the energy of dissolving salts or chemical reactions for heating or cooling beverages and foodstuffs. Based on commercially available beverage containers and food devices of this type, the theoretical temperature variation that should be reached after the process (chemical reaction or dissolution of a salt in water) has been studied, and the experimental values obtained are reasoned, considering, for example, the approximations made in the theoretical calculation. For all this, various aspects of thermochemistry are considered, such as heat of reaction or dissolution, specific heat of a substance, etc. (Oliver-Hoyo, Pinto and Llorens, 2009; Prolongo and Pinto, 2010). The design of a beverage container with these characteristics, marketed in recent years in Spain, is shown in Figure 6, which was made by a group of students using notions they learn in another subject (Drawing). Apart from thermochemical considerations, the example favors the creativity of students and the general public, who propose improvements in the manufacture of the container or how to make similar devices to cool a beverage. In addition, the Science-Technology-Society approach is promoted by discussing the increased costs of this type of packaging (transport, manufacturing…) and its greater difficulty for recycling compared to conventional ones.

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An example of work proposal ideas for students, while inviting them to look at the information on a commercial self-heating container, is:

a.- Describe the container (type of components, compartments, appearance of the calcium oxide, etc.), make a drawing to illustrate it and briefly explain its operation, including the adjusted chemical reaction that allows heating the beverage, the justification for using colored water and the need to wait three minutes (as indicated in the instructions) or other aspects considered of interest.

Figure 6. Diagram made by first-year undergraduate students of a self-heating beverage container. Own elaboration based on a drawing made by the author's students.

b.- Calculate the moles of calcium oxide and water that can take part in the reaction, pointing out clearly which of these substances is the limiting reagent. Determine the masses of substance (in g) of the excess reactant and products that can be formed.

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c.- Find in appropriate references the values of standard enthalpy of formation, at 25°C, in kJ/mol, of the following substances: calcium oxide (s), water (l) and calcium hydroxide (s). It is recommended to search at least in a bibliographic reference and in another one of some Internet address, presenting the different values in an appropriate table.

d.- With the data of the previous section and the results of section b, calculate the heat (in kJ) that is given off, theoretically, when the reaction takes place.

e.- Express the initial temperature of the beverage (the classroom temperature) and calculate the approximate temperature (in °C) it would reach, considering the following specific heat values (in cal/g-°C): water (1.00), calcium hydroxide (0.28) and tinplate (0.12). Consider that the whole container is made of tinplate and that the specific heat of the beverage is approximately equal to that of water.

f.- Compare the final temperature calculated in the previous section with the one that would be reached according to the information provided in the container and with the one that was reached in the classroom. It is recommended to elaborate a table where the three temperatures are collected.

g.- Comment and reason (listing the approximations made) the differences observed in the three temperatures (calculated, suggested by the manufacturer and experimental).

h.- Reason if it would be possible to use the same design to cool a beverage.

i.- Discuss the advantages and disadvantages of this type of packaging, highlighting economic and environmental issues.

j.- Collect any additional comments considered to be of interest, such as the evaluation of the instructions provided on the package or additional information.

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6. Proposals of themes that relate science, history, art, and society

Table 4 summarizes some proposals of possible topics for learning situations, in which science, history, art and society are related. They are original contributions for teachers to approach with their students, combining and interrelating knowledge of science, technology, art, and history. Thus, for example, the Solvay Conferences and other scientific meetings of the early 20th century are an excellent opportunity to introduce aspects of the beginning of quantum mechanics and knowledge of the structure of matter, as well as the history of interwar Europe. Interesting examples associated with these Conferences are: the participation of the Belgian scientist August Piccard, who inspired his friend Georges Prosper Remi (Hergé) to create the character Sylvester Tornasol in *The Adventures of Tintin*; the friendship that was generated in that environment between scientists such as Einstein and Marie Curie; or the participation of the Spanish physicist Blas Cabrera in those held in the 1930s (Pinto, Martín and Martín, 2015; Pinto Martín and Martín, 2016).

There are cases and issues raised that include aspects such as the use of commemorative stamps and ephemeris to introduce and discuss scientific issues, as well as the analysis of works of art. Thus, the contributions suggested in relation to postage stamps recently issued in Spain stand out. Specifically, they were one on the periodic table, as a tribute to the Russian scientist Mendeleev, whose image is inspired by Mondrian's pictorial style (Pinto, 2007), one on Marie Curie (issued in the International Year of Chemistry, 2011) (Pinto, 2011) and another on the tercentenary of the birth (in 1716) of Antonio de Ulloa (Pinto, 2017). In the case of the latter seal, it gave rise to a series of pedagogical proposals to promote greater knowledge of this character. Ulloa stands out in the history of science for the discovery of platinum. But he also participated in an interesting scientific expedition to measure the length of a degree of arc of the meridian, in

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the equatorial zone of the former Kingdom of New Granada, to compare it with another measurement made in Lapland. This was intended to elucidate the type of flattening of the Earth. Figure 7 shows students working with different educational tools (computer, periodic table, mobile devices, etc.) on questions about the life and work of Antonio de Ulloa. Different scientific and historical perspectives on the figure of the mining engineer and chemist Andrés Manuel del Río, discoverer of vanadium, were also addressed (Pinto, 2021).

Table 4. Proposals of topics to relate science, history, art, and society, validated for contextualized, multi and interdisciplinary learning of STEAM domains.

References are included in the text.

Topic	**Aspects studied and characteristics**
Science in the press.	Science-Technology-Society implications, social image of science, fostering critical thinking, STEM areas in the media, journalism.
Solvay conferences and their context. Solvay's biography.	Contextualization of science, chemical industry, scientific meetings in the early 20th century, quantum mechanics, structure of matter, Science and Society, science as a collective task, World Wars, history....
Lugol's reagent.	Biography of physician Lugol, medical applications of the reagent, health.
Alan Turing's	Biography of Alan Turing, contributions to chemistry, origin of electronics, mathematical patterns of Turing.

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contributions.	
Avogadro's constant.	History of science, biography of Avogadro, the concept of mole, Avogadro's number or constant.
Chemical weapons.	Characteristics of chemical weapons, World War I, weapons destruction programs and agencies.
Stamp on the periodic system.	Background of the periodic system, Mendeleev's eka-elements, electronic configuration, history of science, philately, art.
Stamp on Marie Curie.	History of science, Marie Curie's visits to Spain, radioactivity, philately, women scientists, Silver Age of Spanish culture.
Science and a centennial pictorial collection.	MAXAM pictorial collection ("explosives" calendars), use and history of explosives, Alfred Nobel, art on scientific facts, social implications of science, posters.
Light scattering: sculpture.	Recycling materials, light scattering, Newton's experimentum crucis, optics, art about aspects of science.
Colladon's apparatus and optical fiber.	History of Colladon's apparatus, light reflection and Snell's law, refractive index, fiber optics, illumination of water fountains.
Scientific work of Antonio de Ulloa.	Discovery of platinum, scientific expeditions, measurement of longitude of the Earth's meridian, canal of Castile, mathematics, geography, metals.

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Scientific work of Andrés del Río.	Mineralogy, chemical elements, metals, history of Spain and America, Spanish Enlightenment.
The Altarpiece of the Independence.	Contemporary art (Mexican muralism), history of science, history of Spain and Mexico.
Space flights.	Science and technology, astronomy.
Genesis and bases of the periodic table.	History and implications of the periodic table, Spanish Enlightenment, discoveries of chemical elements by Spaniards.
Educational and didactic walks.	Service-learning, Silver Age of Spanish culture, the Spanish Enlightenment, history of Madrid. Discovery of chemical elements.

Another novel example proposed and used is the collection of paintings of the company *Unión Española de Explosivos* (today MAXAM), which serve to delve into the importance of explosives in modern society, and varied approaches such as the history of Spanish posters, the origin of the company (founded by Alfred Nobel himself), the relationship between science and technology (safe treatment of nitroglycerin through dynamite), ethics and science (use of explosives with war motifs), etc. Painters of the stature of Julio Romero de Torres have been involved in the collection (Pinto and Garrido-Escudero, 2016).

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Figure 7. High school students discussing, with different educational tools, aspects related to the discovery of platinum and other achievements of Antonio de Ulloa. Own elaboration.

Other topics addressed are the historical background of Avogadro's constant (Pinto et al., 2011) and of the so-called "Lugol's solution" (with important implications in medicine) (Martín, Martín, and Pinto, 2013), the multidisciplinary implications inherent in spaceflight (Martín and Pinto, 2019), and the contributions to physics and chemistry of Alan Turing (Martín, Martín, and Pinto, 2012), one of the fathers of computer science and cryptography.

To celebrate the declaration in 2015 of the International Year of Light and Light-Based Technologies, a paper was carried out on the historical study of the apparatus known as Colladon's apparatus (Martín *et al*., 2015b). This Genevan engineer discovered in the mid-19th century that light could be confined in the curved shape of a water jet. The explanation, by total reflection, is easily understood by pre-university students, in application of Snell's law of refraction. Moreover, it is the basis for understanding the functioning of "light sources" and

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fiber optics, so widely used, and well known today. In relation to light, with the collaboration of students and teachers, an artistic exhibition was carried out in which a giant sculpture was made to commemorate Newton's emblematic experiment on light scattering through a prism, with recycled material (Díaz *et al*., 2015). In relation to other aspects included in Table 4, the proposals on the use of current news items to introduce scientific aspects are highlighted (Pinto, 2002).

In 2019, the International Year of the Periodic Table of the Chemical Elements was celebrated, an event that was a great opportunity to address different aspects of relations between history, art, science, philosophy, creativity, and technology, for which several didactic tools were developed (Pinto, 2019; Pinto et al., 2019; Pinto, Martín and Prolongo, 2020). As an example, it was explained how to introduce the life and work of Fausto Elhuyar (co-discoverer of wolfram with his brother Juan José) and Andrés del Río (discoverer of vanadium), through the Independence Altarpiece, a work by Mexican muralist Juan O'Gorman (Pinto, 2022b).

Finally, and as an example of the generation of educational tools for inter and multidisciplinary learning in STEAM fields, the preparation of didactic and informative walks is discussed, where students can participate as assistants and as "guides" (using in this case the Service-Learning modality). Specifically, during the current year, the author of this work leads a group of students and university professors who are designing two walks around Madrid, with the titles: "The 'Spanish' chemical elements: three landmarks of the Enlightenment period (18th century) and early 19th century" and "The 'highs of the racetrack': an emblematic area of the Silver Age of Spanish culture" (1868-1936). (1868-1936).

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7. Conclusions

In this work, we have summarized many contributions that can serve as inspiration for teachers of different educational stages. With them, we have shown the possibility of introducing interdisciplinary and multidisciplinary activities that can involve teachers from different disciplines, with which to promote active and contextualized learning in students in their daily lives. In some cases, some contributions have simply been cited, from the field of science, with the idea that teachers of other subjects can find and devise connections.

The students' response to these didactic tools, generally positive, is not always as enthusiastic as might be expected. Some, at times, prefer simpler ways of learning, in which the merely transmissive and repetitive aspects prevail, and they feel insecure when they have to look for data, make approximations, offer results that do not have to be only one concrete one, etc. Some teachers also feel a certain insecurity with this type of activities, which are more open than conventional ones. But, both among students and teachers, the aim is to encourage training that promotes more meaningful learning, through inter- and multidisciplinary approaches, in line with the problems inherent in everyday reality. And this is something that is not always appreciated in the short term. In addition, with many of these tools, students discover how sustainable development objectives are addressed in their subjects.

These are examples, in any case, of ideas that can serve as a basis for designing learning situations with which students “learn to learn” not only STEM or STEAM subjects, but also the contents of the different subjects.

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