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Grau de Química

Treball Final de Grau

Development of a mixed experimental box (ChemKit) (physical and online) of chemistry for secondary school.
Desenvolupament d'un maletí (ChemKit) experimental mixt (físic i online) de química per a secundària.

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June 2022

Universitat de Barcelona
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Campus d'Excel·lència Internacional

El educador es el hombre que hace que las cosas difíciles parezcan fáciles.

Ralph Waldo Emerson

Gràcies al Jordi per haver proposat aquest projecte i haver-me deixat ser-ne partícip, així com per guiar-me durant el procés i encoratjar les meves propostes. Molt agraïda d'haver pogut desenvolupar les bases d'un projecte que espero que algun dia s'acabi portant a la pràctica.

REPORT

IDENTIFICATION AND REFLECTION ON THE SUSTAINABLE DEVELOPMENT GOALS (ODS)

The Sustainable Development Goals (SDGs) are a set of global goals determined by the United Nations to procure just and sustainable conditions for everyone. 17 SDGs have been deployed to improve situations ranging from poverty to climate change and gender equality.

Out of the 5 areas these SDGs have been grouped into (People, Prosperity, Planet, Peace and Partnership) this work is related to People. More concretely, this project is directly connected to SDG 4, the Quality Education goal. It aims to “ensure inclusive and equitable quality education and promote lifelong learning opportunities for all”.

This project aims accessible and affordable teaching methods based on experimentation. It has been conceived as a new learning tool to promote lifelong learning opportunities. In addition, the ChemKit has been developed to be as economic as possible. Therefore, reachable to more population.

Besides, the experiments that have been elaborated are grounded on different chemical fundaments that can easily be associated with other SDG. An example is water electrolysis and its connection to SDG 6 and 7.

Figure 1. Sustainable Development Goals, infography obtained from the UN.

CONTENTS

1. SUMMARY

Chemistry is a discipline introduced during the first years of secondary school as a compulsory subject and continues in “batxillerat” as an optional subject. These years are fundamental to directing students toward the scientific world. Unfortunately, this branch of science is usually not welcomed due to how it is presented to students. Because of this, it is essential to find new ways to capture the attention of the scholars and make the study more meaningful.

Experience-based learning (ExBL) is a methodology based on first-person experimentation of the student and the assimilation of concepts from these. The ChemKit project proposes an experimental briefcase with various experiences related to the field of chemistry prepared to be developed by students autonomously. It is mainly aimed at 3rd and 4th of “Educació Secundària Obligatòria” (ESO) and “batxillerat” students.

The challenge of this project is to introduce a new teaching method in classrooms to bring chemistry closer to students, connecting it to everyday phenomena and making the learning more significant and lasting.

Keywords: Experience-based learning, ExBL, significant learning, autonomy, chemistry, briefcase, ESO.

2. RESUM

La química és una disciplina que s'introdueix durant els primers anys de secundària com a assignatura obligatòria i que continua a batxillerat com una assignatura optativa. Aquests anys són clau per encaminar els estudiants cap al món científic. Malauradament, aquesta branca de la ciència sovint no és benvinguda, conseqüència del format en què es presenta. Per aquest motiu cal buscar noves vies que captin l'interès de l'estudiant i que facin l'estudi més significatiu.

L'aprenentatge a base d'experiències és una metodologia que es basa en l'experimentació en primera persona de l'estudiant i l'assimilació de conceptes a partir d'aquestes. El projecte ChemKit proposa un maletí experimental amb diverses experiències relacionades amb l'àmbit de la química preparades per ser desenvolupades pels alumnes de forma autònoma. Està enfocat principalment a estudiants de 3r i 4t d'Educació Secundària Obligatòria (ESO) i batxillerat.

El repte que presenta aquest projecte és introduir una nova sistemàtica de treball a les aules per apropar la química als estudiants, relacionant-la amb fenòmens quotidians, i fer que l'aprenentatge sigui significatiu i durador.

Paraules clau: aprenentatge a base d'experiències, aprenentatge significatiu, autonomia, química, maletí, ESO.

3. INTRODUCTION

Everyone presented a curious mind when they were younger. Children are constantly experimenting and asking questions about everything that surrounds them. But, as they get older, all these questions tend to fade away. Why does this happen? Why do kids lose interest in the working of the universe? How is it possible that most of them turn away from science instead of facing it and looking for the answers to their questions?

Science is firstly introduced to kids during elementary school. Small doses of information are given through simple demonstrations done by the teacher and some theoretical subjects. These experiments are characterized by their spectacularism but do not delve into their secrets. These experiences catch kids' attention and keep them wondering about the world for a little longer.

As they grow up, other questions arise, and new interests appear. The spectacularism of those experiments presented in elementary school alone is not enough to keep them interested in science. Basic courses in Biology, Chemistry and Physics are introduced during the first years of high school, willing to answer some of the questions asked a few years ago and keep them on the path of science. Unfortunately, all these subjects are based on theoretical knowledge. Hundreds of scientists' names, dates, theories, formulas, and abstract concepts are presented to students. A lot of information is given to them, and they feel overwhelmed by all the ideas they can't relate to. The lack of real-life examples and experimentation makes understanding and learning more difficult, and students become disenchanted with science.

Chemistry, the field of interest in this work, is introduced during the first years of high school, as has been said before. It is usually not welcomed by students. This subject is mainly based on theories and concepts that are pretty difficult to understand due to their abstraction and that are seldom paired with experimentation, which would make the learning more attractive. Simple, practical sessions and experiments would be enough to help students visualize what they are studying, but these are rarely found in the curriculum.

On the other hand, chemistry kits for home, such as the famous "Quimicefa", are easily found in toy stores. Many parents have bought these kits to start their children on the path of science. Other families have bought them for educational playing to entertain their children while learning. But are these kits really educational or just playful?

There are many different kits, addressed to different ages and with different difficulty levels. But, the common feature between them is the focus on the spectacularism of the results rather than on the basis of the experiments. Therefore, they don't have a pedagogical purpose.

So, on the one hand, we have an education system that is focused on the theoretical basis of science but lacks experimentation. On the other hand, we have scientific kits focused on the results but lack academic context. Both theoretical basis and experimentation are necessary for a good understanding of science. Then, what if we mix both and pursue learning based on experiences?

3.1. EXPERIENCE-BASED LEARNING (EXBL)

John Dewey was the first to suggest that experience played a significant role in learning. He considered that learning from experience or learning by doing was a key factor for a successful education(Dewey, 1986).

The most influential model of experiential learning or experience-based learning (ExBL) is the one suggested by D.A. Kolb in 1984 (Kolb, 2014). This experiential learning theory consists of a four-stage learning cycle:

1. **Concrete experience.** The learner is involved in a new experience.
2. **Reflective observation.** The learner makes observations on the new experience.
3. **Abstract conceptualization.** The person learns from the experience. The reflection gives rise to a new idea or a modification of an existing abstract concept.
4. **Active experimentation.** The newly created or modified concepts give rise to experiments. The learner applies the ideas to the world around them to see what happens.

This cycle presents an integrated process since all stages are mutually supportive. It is possible to enter the cycle at any stage and follow the logical sequence, but for the learning to be effective, a person must go through all four steps (McLeod, 2017).

ExBL framework adopts the constructive alignment approach pioneered by Biggs. According to the constructive component, students learn better through active engagement than passive exposure. The meaning of what is being studied is constructed via relevant learning activities.

The alignment refers to the linkage between learning objectives and learning activities (Biggs, 2003).

Experience is not only an observation, something passive, but an active engagement with the environment, of which the apprentice is an important part (Boud et al., 2011).

Students learn from experiences that naturally interest them. Therefore, their motivations and interests will capture much of their attention during their learning years.

For learning to be meaningful and efficient, students need to be directly involved with the objects being studied. There must be time for discoveries, experimentation, and knowledge consolidation, as well as for students broaden their minds along with their teachers.

3.1.1. ExBL in the educational system

The concept of experiential learning has been around for decades, and it has been implemented in different areas. Depending on the field of study and the content being taught, the experiences used in this methodology can vary. Internships, volunteering, independent research, experiments, etc., are all examples of it.

The dominant educational model is traditional learning, based on presenting information to the student, who has a passive role. This learning-teaching method is being questioned since it has remained practically unchanged while society has been changing and transforming.

ExBL is making its way through higher education. Different disciplines have already implemented this methodology and are studying the resulting acquisition of skills and knowledge (Dornan et al., 2007; Matsuo et al., 2008). The truth is that more and more careers are taking on the Experience-based learning.

Even so, this methodology hasn’t been implemented yet in scientific degrees such as Chemistry. These degrees indeed include laboratory experiences and practical work, but these are not based on ExBL. These practices consist of a mix of all the contents done in a subject and are done after several theory sessions. In this way, it is impossible to relate, assimilate and retain all the concepts.

Elementary and secondary schools are starting to implement experiential learning. Simple experiences are presented to students in elementary school, which they have to analyze and hypothesize about. In secondary school, learning from group projects and problem-solving experiences are becoming more frequent.

3.2. BENEFITS OF EXBL

Inspires creativity. Since there is no single answer to fieldwork, learners can approach their work from different angles.

Fosters community. Learners can see the impact of what they are studying on the world. Teamwork also fosters relationships.

Invites problem-solving. Learners will encounter different situations that might need solving before continuing the experience. They will be forced to interact with other people, apply different techniques and consult various resources.

Teaches the value of mistakes. Experiential learning involves trial by error. Students will find out there are methods that work better than others. They learn not to fear mistakes but to benefit from them.

Accelerate learning. The act of practicing a skill strengthens the neural connections in the brain. Experiential learning requires hands-on activities that enhance these connections and improve retention and accelerate learning.

3.3. EDUCATIONAL KITS

Educational kits enable us to incorporate crosscutting concepts, science and chemical practices and disciplinary core ideas. These kits incite imagination and inspire kids' creativity. They are a valuable tool to keep students learning throughout the school year and improving their knowledge. Educational kits teach critical thinking skills, drive home scientific concepts based on real-world issues, and enable students to experience the feeling of curiosity and discovery.

Educational science kits make learning more effective for students. Learning science experimentally helps students absorb more knowledge and ensures that the learning stays in mind for a longer time. Furthermore, because these kits are hands-on, children can enjoy and have fun while experimenting. Thus, these kits promote experiential learning.

Educational kits can vary in topics and are made to supplement textbooks, especially in science subjects. They simplify the complex notions explained in the books and demonstrate principles that might be difficult to understand only by reading.

4. OBJECTIVES

4.1. GENERAL OBJECTIVES

Facilitate teaching and stimulate the acquisition of scientific knowledge in secondary school.

Raise awareness of the importance of chemistry in our lives.

Development of an educational kit specialized in Chemistry.

4.2. SPECIFIC OBJECTIVES

Development of teaching units based on practical experiments to strengthen the theoretical concepts explained in class.

Encourage students' autonomy by developing experiments that require low supervision and improve their performance in scientific subjects.

Enhance the students' interest by using technologies and draw their attention to the scientific field.

Stimulate students' motivation and desire to learn more.

Relate everyday facts to scientific concepts.

5. THE CHEMKIT

5.1. ACADEMIC CONTEXT

The ChemKit has been designed as a tool to complement the theoretical concepts taught in Chemistry courses between 2nd of ESO and "batxillerat". It offers a series of interdisciplinary teaching modules assembled by experts.

The kit aims to help students understand and relate to those abstract ideas that are presented to them, like gas laws, chemical equilibrium or solubility, and to enable them to see the connection between these notions and their everyday life.

5.1.1. Curricular adaptation

The curriculum established by "Departament d'Educació de la Generalitat de Catalunya" for the 2021/22 academic period has been studied and taken under consideration for developing this chemistry kit.

This work is focused on the scientific and technological field and its basic skills and key concepts. The topics of the different experiments of the kit follow the contents determined by the official authorities for the Chemistry courses Direcció General d'Educació Secundària Obligatòria i Batxillerat, 2021a)

The basic skills of the scientific and technological field are divided into four dimensions which are subdivided into different competencies or skills (Direcció General d'Educació Secundària Obligatòria i Batxillerat, 2021b). Just two of the dimensions and six competencies have been considered fundamental to this project:

- Dimension of investigation of natural phenomena and everyday life.
    - Competence 1. Identify and characterize the physical and chemical systems from the perspective of models, to communicate and predict the behavior of natural phenomena.

  - Competence 4. Identify and solve scientific problems that may be investigated in the school environment that involves the design, conduct and communication of experimental research.
  - Competence 5. Solve issues of daily life by applying scientific reasoning.
  - Competence 6. Recognize and use the processes involved in elaborating and validating scientific knowledge.
- Dimension of environment.
  - Competence 10. Make decisions based on scientific criteria to predict, avoid or minimize exposure to natural hazards.
  - Competence 11. Adopt measures with scientific criteria that prevent or reduce the environmental impacts arising from human intervention.

The different experiments have been adapted to the concepts taught in class and adjusted so that they can be done with little supervision. The experiments are expected to be conducted by students. The function of the teacher is to act as a support, clarify concepts and methodology, and help during the experimental procedure only under challenging steps.

The ChemKit is focused on a qualitative analysis of the different phenomena studied. A qualitative analysis enables students to better understand what is happening.

All the experiences have been designed in a suitable way to use as many materials and reactants that can be found in every house or drugstore as possible. Thus, the price of the kit is reduced, and so is the environmental impact since many reactants are environmentally friendly in the quantities used.

5.1.2. Teaching recommendations

The teacher must prepare the experience before it is developed in class. The teacher's guide must be read beforehand to check that the concepts involved in the experiment are related to the ones taught in class. Moreover, the person in charge of the group must ensure that they have a room long enough to do the experiment and that all the material necessary but not included in the kit is available.

The idea is that students work on their own, in small groups, but without the teacher's help. They are given enough information to develop the experiments without help. The teacher must act only as a support to resolve questions and help with complex steps of the procedure. In any case the teacher should perform the whole experiment.

Regarding the curriculum, different theoretical concepts should have been previously worked on in class for each experiment. Table 1 shows the notions that should have been introduced at least beforehand.

Table 1 Theoretical concepts that should have been worked before the experiment.

Experiments	Previous knowledge
“Els gasos”	- Matter and states of matter. Gas properties. - Kinetic theory - Gas laws - Ideal gases
“La quimioluminiscència”	- Matter and its structure. - Atomic models - Electronic configuration
“La cromatografia”	- Mixtures - Mixture separation techcniques - Paper chromatography
“L’electròlisi de l’aigua”	- Chemical reactions - Oxidation-reduction reactions - Batteries and electrolysis
“Els indicadors de pH”	- Chemical reactions - Acids and Bases - Chemical indicators - pH and acidity
“L’equilibri químic”	- Chemical reactions - Reversibility of reactions - Chemical equilibrium - Le Chatelier’s principle
“La cinètica de les reaccions químiques”	- Chemical reactions - Reaction rate - Collision theory
“La solubilitat”	- Chemical reactions - Chemical equilibrium - Mistures and solutions - Solubility

5.2. Development

A benchmarking study was first done to analyze similar products that can be found. Various websites specialized in experimental kits were studied. Examples of these sources of information are Home Science Tools (https://www.homesciencetools.com), Fisher Science Education (https://www.fishersci.com)or MEL science (https://melscience.com) Similar works done by "Universitat de Barcelona" were also taken under consideration (Masuet et al., 2014).

Two different kinds of products were found:

- Complete chemistry kits. These include several experiments with reactants and material needed. Instructions are also included. These kits are mostly recreational. Figure 2 shows an example of this kind of kits.

Figure 2. Complete introduction to Chemistry, infography obtained form Home Science Tools

- Individual experiments. Most of these include reactants and instructions, but no materials. Figure 3 shows an example of this kind of kits.

Figure 3. Cool blue light experiment kit, infography obtained from Home Science Tools

Different aspects of these products were taken under consideration during the study. These features are:

- Chemical aspect worked in the experiment.
- Price
- Need of supervision
- Accessible manual of instructions
- Included materials

Up to 60 experiments were considered. Afterwards, these experiments were categorized according to the chemical aspects where they focused. This classification allowed a generic view of the chemical foundation of the experiments and which of those seemed more popular.

The documents regarding the market study and the classification of the experiments can be consulted using the QR code in Figure 4 or clicking here.

Figure 4. QR code that redirects to a Google Drive folder containing documents regarding the market study.

The selection of the experiments was done according to the chemical foundation, the difficulty of the procedure and the access to the instructions of the considered experiments. Eventually, eight different experiences, which will be commented later, were selected for this project.

The experimental procedures have been elaborated in different ways. Some are based on the experiments that were found previously, others have been adapted in order to reduce the difficulty of the procedure or decrease the price, and some are the result of the mixture of different experiments.

The whole kit has been adapted to accomplish three requisites:

- Affordable
- Eco-friendly
- Suitable for students with little supervision

It has been considered that a qualitative analysis of the experiments is better if it enables the students to acquire a better understanding of what is happening. A quantitative analysis, on the other hand, focuses on the numerical results and students tend to focus on that rather than focusing on what is going on. Besides, quantitative analysis requires more expensive reactants material, such as volumetric material, which would increase a lot the price of the kit.

5.3. Kit description

After considering other similar kits, as the Nanokit (https://nanoeduca.cat/ca/nanokit/) it was decided that the ideal number of experiments was eight. Thus, a variety of topics regarding the chemistry field could be explored at the same time it allows the introduction of new modules in the future. Furthermore, this proposal makes it economically viable and realistic.

Figure 5. Nanokit, infography obtained from Nanoeduca.

Each experience is individual, meaning that they are not directly connected with each other and are expected to be carried out in different sessions. It is recommended that the theoretical concepts regarding the experiment have been introduced in class beforehand.

5.3.1. Contents

The kit contains a teacher's guide, the student's guide and materials and reactants.

The teacher's guide includes all the experiments. The information for each experiment is divided in sections:

1. Curricular adaptation. It is presented as a summary table.

2. Recommendations. Here there are suggestions in relation to the work that should have been done before the students are encouraged to do the experiment.
3. Introduction. A question that connects an everyday phenomenon to a chemical concept is presented to catch the attention of the student.
4. Theoretical concepts. Explanation of the notions related to the experiment.
5. Materials, reactants, and security measures. There is a specification of the materials and reactants that are not included in the set and the security measures that need to be followed during the experiment.
6. Indicators of danger. This section includes the dangers of each reactant used in the experiment.
7. Experimental procedure. Step by step explanation of the method that is going to be followed by the students.
8. Waste management. Containers for waste management are included with the kit. In this section, teachers can find the indications for each residue. These will be treated at the university once the kit is returned. It is important that the teacher emphasizes the significance of a responsible waste management.
9. Assessment.

The students' guide consists of a series of cards that are divided by colors for each experiment. Every deck of cards includes:

1. Introduction. A question that connects an everyday phenomenon to a chemical concept is presented to catch the attention of the student.
2. Theoretical concepts. Explanation of the notions related to the experiment.
3. Materials, reactants, and safety guidelines.
4. Experimental procedure. The method is explained step by step so that it is easy to follow by the student.
5. Waste management.
6. Assessment.

Figure 6 shows an example of the general structure of each section that can be found in the deck of an experiment.

Each experiment is identified by a color. Therefore, each deck of cards matches the color of the experiment. Figure 7 shows the palette of colors used.

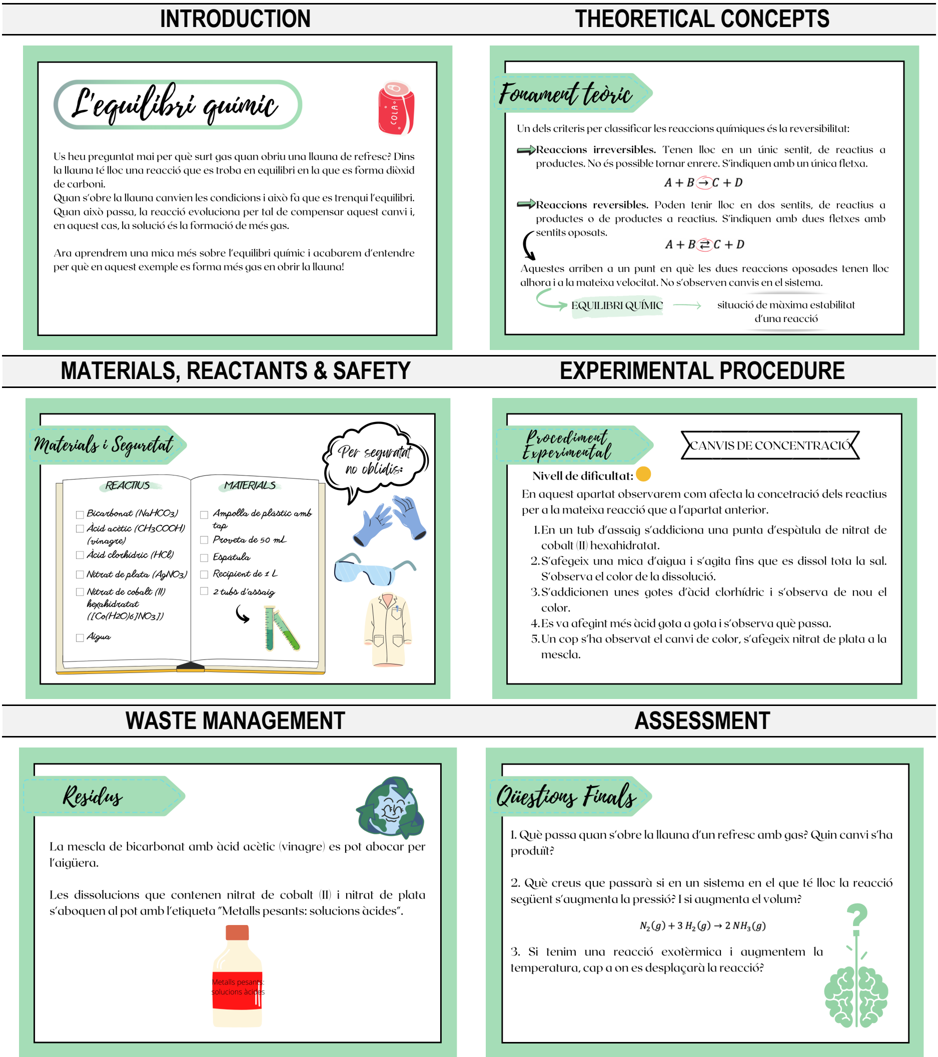

Figure 6. Example of the general structure of each card of the deck.

Figure 7. Color palette of the experiments

The whole students' material for one of the experiments can be consulted in Appendix 1. The rest of the experiments and the teachers' guide can be consulted using the QR code in Figure 8 or clicking here.

Figure 8. QR code that redirects to a Google Drive folder containing the teachers' and students' guide.

Table 2 specifies the totality of materials and reactants that are included in the set and those that are needed but not included.

Table 2. Total materials and reactants needed for the 8 experiments, classified according to whether they are included in the kit or not.

	REACTANTS	MATERIALS
INCLUDED	Chlorohydric acid	1 x 125 mL Erlenmeyer flask
	Cobalt (II) nitrate hexahydrate	2 x 100 mL beaker
	Effervescent tablets	2 x 250 mL beaker
	Food coloring (blue, red and yellow)	2 x Crocodile clips
	Luminol	2 x stainless steel electrodes
	Manganese (IV) oxide	2 x test tubes
	Phenolphthalein	3 x 500 mL beaker

	Potassium bromide	50 mL graduated cylinder
	Potassium hexacyanoferrate (III)	6 V battery
	Silver nitrate	Balloons
	Sodium bicarbonate	Chromatography paper
	Sodium hydroxide	Cork
	Sodium sulfate	Elbow pipe
		Filter paper
		Funnel
		Laboratory clock glass
		pH indicator paper
		Plastic or silicone tube
		Spatula
		Wood sticks
NOT INCLUDED	Acetic acid (vinegar)	1 L plastic container
	Ammonia	Candle
	Candy (M&)	Clear plastic cups
	Distilled water	Paper clips
	Hydrogen peroxide 30%	Plastic bottle
	Table salt	Scissors
	Turmeric or curry	Support and clamps
	Ethyl alcohol	
	Dish soap	

The distribution of materials and reactants per experiment can be consulted in Appendix 2.

5.3.2. The experiments

This set includes 8 different experiments, each one related to a different theme. All of them are related to topics that at some points are introduced in class from second year of high school. Some of the topics might not be worked in depth during this period, but the experiment can be useful to clarify some aspects or introduce new ones, as a way to encourage the most curious minds.

The experiences that have been developed are the following:

1. "Els gasos". This experience is focused on the gas laws. Boyle-Mariotte's, Gay-Lussac's and Charles' laws are briefly explained in the theoretical concepts and

worked in separate experiments. The kinetic molecular theory is also explained. There is a fourth experiment to work the ideal gases' law.

2. "La quimioluminiscència". The topic of this experiment is not directly found in the curriculum, but it is closely related to others that can be found in it. This experiment has been thought of as a complement once the atomic models and electronic configuration have been explained. Chemiluminescence is a very interesting phenomenon that easily catches the attention of the student. Because of this, it is useful to help settle different concepts regarding the atomic models and encourage the most curious to keep investigating.
3. "La cromatografia". Chromatography is not deeply studied in secondary school, but can be introduced when working on mixtures and separation techniques. The basis of this technique is explained in the lightest possible way, commenting on the phases, how the components get separated and the retention factor. This experiment is appealing because students can easily relate to the phenomenon, since they have probably found themselves with damaged drawings or homework due to the spillage of some liquid.
4. "L'electròlisi de l'aigua". This experience focuses on oxidation-reduction reactions. These chemical reactions are superficially introduced in 3rd and 4th of ESO. There is a brief explanation of oxidation and reduction, as well as of batteries and electrolysis. The theoretical concepts do not delve into oxidation numbers or half-reactions.
5. "Els indicadors de pH". Acids and bases are lightly introduced in 3rd and 4th of ESO. The theoretical concepts revise acids and bases, the concept of pH and chemical indicators. This is a very simple experiment to determine the acid or basic behavior of different compounds.
6. "L'equilibri químic". This experience is centered in more advanced concepts. It is recommended for 4th of ESO and "batxillerat". The theoretical concepts revise reversibility of reactions, chemical equilibrium, and Le Chatelier's principle. There are 3 different experiments to study the effect of changes of volume, temperature and concentrations and observe the studied principle.
7. "La cinètica de les reaccions químiques". This experience is mainly pointed to "batxillerat". The aim of this section is to study the collision theory and the factors that

affect the reaction rate. There are 3 different experiments to observe the effect of physical state, temperature and catalysts.

8. "La solubilitat". In this experience, advanced concepts are presented. It is recommended for 4tf of ESO and "batxillerat". Concepts such as saturated solution and solubility are studied in this section. There are two experiments based on the common ion effect and the primary salt effect, both explained in the theoretical concepts.

5.3.3. How it works

The teacher needs to read the information of the experiment before the session, to assure all the extra material is ready for the experiment and to adjust the time. It is recommended that the topic of the experiment has been worked in class previously or, at least, it has been introduced.

Ideally, the students are divided into groups of 4 or 5, and they are given the cards of the experiment. They first read the introduction card, where an everyday life situation related to the experiment is presented. Secondly, each group works on the theoretical concepts on their own. The cards provide a simple basis and a series of QR codes that lead to different websites with more information or examples to clarify the concepts. Next, students move forward to materials, reactants and safety guidelines, where they need to check they have all they need to proceed. The following cards contain the experimental procedure. The method is explained step by step. In some cases, students can visit a website to check the procedure. Anytime there is a difficult or dangerous step, a clarification is made to let the students know that they need to ask the teacher for help. After the experimental procedure, there is a card regarding the waste management that needs to be done. Finally, a series of questions are suggested for the student to answer.

The assessment of the session can be done through the questions at the end of the experiment, or the teacher can ask for extra activities.

5.3. Online Support

A provisional website has been created with Google Sites as an online support for the kit. This site makes the teaching materials accessible for everyone.

The URL to access the website is https://sites.google.com/view/thechemkit/.

The general idea of the online support is to hold all the experiments that have been developed and those that might be introduced in the future.

Ideally, it will also contain the information (for example, where the reactants or materials can be found, places or institutions that hold related practical sessions, etc.) needed for experiments whose development might be expensive and prevents them from being included in the physical kit.

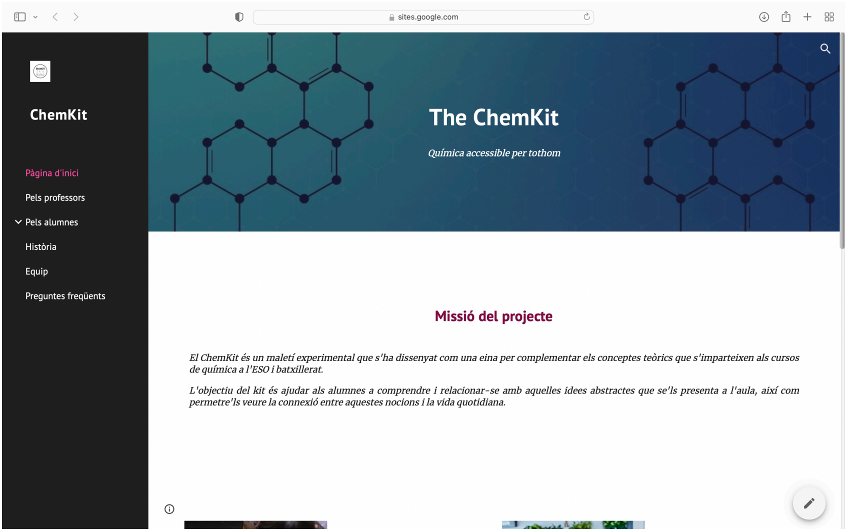

Figure 9. Homepage of the The ChemKit website.

6. THE FUTURE OF THE CHEMKIT

6.1. THE PROJECT

The ChemKit has a cost and needs some source of funding. In this section, both budget and possible financing of the project are analyzed to determine its viability.

6.1.1. The Budget

To estimate the budget, the reactants and materials listed as included in the kit that are shown in Table 2 have been considered. Since the reactants are needed in very small quantities, but they need to be bought in bigger amounts, small bottles to divide each reactant for different kits must be bought as well. Given that there has to be a waste management and the entity responsible will be the university, the kit needs to go with waste containers that are properly labeled. These containers are also considered in the budget.

The prices have been taken from websites specialized in laboratory material for educational use and such as Ibdciencia (https://www.ibdciencia.com), Leboriz (https://www.leboriz.com) and Juvasa (https://www.juvasa.com).

The time spent developing the teaching material, organization and assembly have been considered as well.

As it has been said, reactants have to be bought in big quantities like liters and kilograms or half kilograms. Because of this, the estimated price for the development of just 1 kit will be pretty different from the cost of more kits.

In this case it has been studied which would be the cost for 1 kit, 5 and 10. It has been checked that the more kits developed, the lower the price per unit.

Table 3 shows the total estimated budget.

Table 3. Total estimated budget for 1 and 5 kits.

	Cost for 1 kit (€)	Cost for 5 kits (€)	Cost for 10 kits (€)
Reactants	444,01	900,48	1545,77
Materials	242,83	603,77	1055,55
Workforce	2760,00	3600,00	4400,00
TOTAL BUDGET	**3463,36**	**5104,25**	**7001,32**
UNIT PRICE PER KIT	**3463,36**	**1020,85**	**700,13**

The budget breakdown can be consulted in Appendix 3.

6.1.2. The funding

For the purpose of developing the ChemKit, it is necessary to look for a source of investment to be able to finance the project.

Two different sources of funding could be considered for this project: private organizations or public funding.

6.1.2.1. Private funding

Private funding is based on chemical companies, Catalan or not, or foundations.

There are several chemical companies that could invest in the project. Figure 3 shows a few examples of firms and their logos.

Figure 10. Chemical companies and their corresponding logos.

Grifols, S.A.	BASF Española, S.L.	ESTEVE Química, S.A.	Akzo Nobel Chemicals, S.A.

6.1.2.2. Public funding

There are several aids and grants directed towards projects that promote scientific knowledge.

- **FECYT.** This is a public sector foundation. Since 2007, it has made calls for grants aimed essentially to agents of the Spanish science, technology, and business system to carry out activities to promote scientific culture, technology and innovation. The goal is to approach science, technology, and innovation to citizens, improving the scientific and technical education of society at all levels. The 2021 subsidy amounted to about 4000000 euros. The purposes of the aid are the following (Gobierno de España. Ministerio de ciencia e innovación., 2021):
    - Increase the scientific, technological and innovative culture of the Spanish society.
    - Increase the dissemination of the results of scientific-technical research and innovation finance with public funds.

  - Promote and encourage the approach of science, technology and innovation to citizens while shortening distance between this world and society in general.
  - Improve the scientific-technical educations of society at all levels.
  - Promote the active participation of society in scientific dissemination activities.

  This foundation has already subsidized similar projects, such as Nanokit (CRP Alt Penedès, 2017)

- **Barcelona city hall.** In 2020 the city hall of Barcelona started "El pla Barcelona Ciència". This is an initiative to promote scientific knowledge and involve citizens in its progress. This plan encourages everyone to participate and be heard. Some of the objectives of this initiative are the following (Gerència d'Àrea de Cultura & Tinència d'Alcaldia de Cultura, 2021).
  - Strengthen the scientific education programs.
  - Strengthen the activities of disseminations and communication of science to generate critical capacity.
  - Enhance creativity.

  To do so, several grants and aids are offered every year, such as CREA grants and general subventions.

- **Catalan Foundation for Research and Innovation (FCRI).** This entity disseminates research and innovation among society to promote scientific knowledge. Last year, this foundation launched the first edition of the "Call for Grants for the promotion of scientific culture in Catalonia". The aim of this aid is to fund unpublished scientific communication projects in Catalan. The total financial endowment is 200,000 euros, of which 140,000 euros will go to Young Talent (young people under 40) and 60,000 euros to Consolidated Talent (consolidated communicators and disseminators over 40).

Other options could be collaborations with other universities (URV, UdG, IQS, etc.), "Societat Catalana de Química" o "Col·legi Oficial de químics de Catalunya".

6.2. THE CHEMKIT AT SCHOOLS

The ChemKit would be property of the university and it would be loaned to schools.

This project has been thought so that students can live first-hand experimentations. Therefore, it would be ideal that a school could loan around five kits for each session. This way, students would be able to work in groups of five or six, favoring the autonomous work of students.

Since this kit contains different experiments aimed at different course levels, the school could organize a week focused on the use of the kit. For example, a group of 2nd of ESO could use the kit on a Monday morning, and then, in the afternoon, it could be used by 3rd of ESO students. The following day, it could be used by students of 4th of ESO and the next, by the students coursing Chemistry in high school. This way, the school would be optimizing the loan of the ChemKit and instilling experiential learning in several school years.

Regarding the residues, the loan of the kit would include special containers for waste management. Once the school is finished with the ChemKit, they would return these containers as well. Afterwards, the university would take care of the required waste management.

7. RESULTS AND DISCUSSION

Due to the lack of time and funding, it hasn't been possible to develop a physical briefcase and test it in schools. Even so, it should not be difficult to obtain some funding in the future, since this project accomplishes many of the requirements of the aids already mentioned, such as the strengthening of scientific education programs, promotion, and encouragement of the approach of science to society or promotion of scientific dissemination activities.

It has been considered that the ChemKit should undergo an evaluation if it is ever developed. This evaluation would be used to determine the usefulness of the kit, check whether the objectives of the kit are or could be accomplished, and obtain feedback from the faculty.

The next subsection of this work is a proposal of an evaluation method.

7.1. EVALUATION OF THE CHEMKIT

The ChemKit presents three main objectives:

- Significant learning
- Promote students' autonomy in the learning process
- Increase students' interest in science

Therefore, the project must be evaluated regarding these aspects. In addition, the opinion of both teachers and students should be taken under consideration to open a path to improvement.

Significant learning and students' autonomy in the process can be assessed together. The best way to do so is by doing an exam. By taking a test before and after the experiment, both based on the same concepts, traditional learning and ExBL can be assessed and compared. The results of the exams would reflect the concepts learned with each method. An improvement on the grades from the first test to the second one would imply a satisfactory implementation of the method.

Another option to evaluate the learning is working with two separate groups. The same study topic is presented to both groups, but one will be learning by traditional methods and the other one by using the ChemKit. At the end of the session, both groups are examined. The obtained results reflect the effectiveness of each method. In this case, a satisfactory implementation of the ChemKit would be evinced by an equal or better performance on the test compared to the results from the group taught by traditional methods.

To assess the effect of the ChemKit on the students' interest in science a survey can be done, inquiring about the student's opinion.

Finally, to be able to improve the kit and the methodology, teachers should be surveyed about different aspects of the experiment -for instance, if they consider the theoretical concepts are adequate or if the procedure is too complicated- and asked about their opinion and suggestions.

A survey for teachers is proposed in Appendix 4.

8. CONCLUSIONS

There are different chemistry kits, but they are either recreational or not used appropriately. Seldom times these kits are used as complement material in chemistry courses. None of the kits that have been studied are made specially for that purpose.

Even so, it has been proven that a chemistry educational kit can be developed for didactic purposes. It is possible to adapt different experiments to a high school level to promote experiential learning and students' autonomy.

The ChemKit is a completely viable project. In terms of funding, the project meets the requirements for many aids and grants.

An evaluation method is necessary in order to verify that the main objectives are achieved and detect oversights. Moreover, feedback from teachers and students is necessary to improve the methodology.

Unfortunately, the project has not been implemented and no conclusions can be drawn in relation to the efficiency of experience-based learning.

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APPENDICES

APPENDIX 1: TEACHING MATERIAL FOR STUDENTS

Els gasos

Us ha passat mai que després de jugar amb una pilota us l'heu descuidat al sol i quan l'heu anat a recuperar estava més inflada?

Us heu fixat que de vegades la pilota es desinfla durant la nit?

Tots dos fenòmens són conseqüència dels canvis de temperatura que pateixen la pilota i els gasos que conté.

Les lleis dels gasos relacionen la pressió, la temperatura i el volum, i ens ajudran a entendre què és el que està passant !

Fonament teòric

Hi ha 3 estats principals de la matèria: sòlid, líquid i gas. Cadascun presenta propietats diferents.

SÒLID	LÍQUID	GAS
Molècules molt unides	Molècules parcialment unides	Molècules molt separades
Forma i volum propis	Volum propi i s'adapten a la forma del recipient que els conté.	Ni forma ni volum propis. Tendeixen a ocupar tot l'espai disponible.
No es poden comprimir	No es poden comprimir	Es poden comprimir
No flueixen	Flueixen	Flueixen

Existeixen altres estats de la matèria !

PLASMA

Fonament teòric

Existeixen 4 lleis dels gasos que relacionen la pressió, la temperatura i el volum i demostren la relació entre aquestes tres propietats:

Llei de Boyle-Mariotte	Llei de Gay-Lussac	Llei de Charles
Temperatura constant La pressió i el volum són inversament proporcionals.	Volum constant. La pressió i la temperatura són directament proporcionals.	Pressió constant. El volum i la temperatura són directament proporcionals.
Si el volum augmenta, la pressió disminuirà i viceversa.	Si la temperatura augmenta, la pressió també ho fa.	Si el volum augmenta,la temperatura també ho fa.
$p_1 \cdot V_1 = p_2 \cdot V_2$	$\frac{p_1}{T_1} = \frac{p_2}{T_2}$	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Llei dels gasos ideals

Si es combinen les 3 lleis anteriors s'obté l'**equació general dels gasos ideals**

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$

Considerem un recipient tancat on es poden variar la pressió, el volum i la temperatura, però es manté la massa constant, és a dir, el número de mols.

La llei dels gasos ideals relaciona la pressió, el volum, la temperatura i el número de mols d'un gas ideal:

$$P \cdot V = n \cdot R \cdot T$$

on n és el número de mols i R és la constant universal dels gasos.

$$R = 0{,}082\ \frac{atm \cdot L}{K \cdot mol} = 8{,}3\ \frac{Pa \cdot m^3}{K \cdot mol} = 0{,}083\ \frac{bar \cdot L}{K \cdot mol}$$

Teoria cineticomolecular

Per a gasos que es comporten idealment, la **teoria cineticomolecular** ens diu:

- Un gas està format perpartícules molt petites que no es toquen entre elles.
- Les partícules es mouen amb total llibertat perquè no existeixen forces d'unió entre elles.
- Les partícules es mouen en línia recta. Només canvien de direcció quan xoquen amb una altra partícula o amb la paret.
- Els xocs són elàstics, és a dir, no es perd energia i les partícules es continuen movent amb la mateixa velocitat.
- La pressió que exerceix el gas és proporcional al nombre de xocs contra les parets.
- La temperatura del gas és proporcional a la velocitat de les partícules. A major velocitat, més xocs es produeixen i major és la temperatura.

Materials i Seguretat

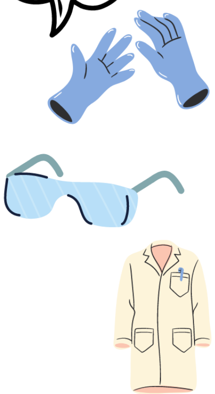
REACTIUS

- ☐ Bicarbonat ($NaHCO_3$9
- ☐ Àcid acètic (CH_3COOH) (vinagre)

MATERIAL

- ☐ Erlenmeyer de 125 mL
- ☐ Proveta de 50 mL
- ☐ Tub de silicona de 30 cm
- ☐ Tub colzat
- ☐ Tap de suro amb forat
- ☐ 2 globus
- ☐ Espàtula
- ☐ Embut
- ☐ Espelma
- ☐ Ampolla de plàstic
- ☐ Suport i pinces
- ☐ Recipient de plàstic transparent de 1L (tipus tupper)

Per seguretat no oblidis:



Procediment Experimental

LLEI DE BOYLE-MARIOTTE

Nivell de dificultat:

1. Es lliga un globus al coll d'un embut sense que s'escapi. Si cal es pot aguantar amb una mica de cinta adhesiva.
2. S'omple un recipient d'1 L amb aigua.
3. S'introdueix la part ample de l'embut en el recipient d'aigua.
4. Es va fent pressió per enfonsar l'embut. Què obsesrves?

QÜESTIONS

a) Escriu en el full d'anotacions què observes.

b) Consulta el QR per acabar d'entendre què està passant.

Procediment Experimental

LLEI DE GAY-LUSSAC

Nivell de dificultat:

1. Es cobreix la boca d'una ampolla de plàstic amb un globus.
2. Es prepara un recipient amb aigua molt calenta i un altre amb aigua molt freda.
3. S'introdueix l'ampolla amb el globus en el recipient amb aigua calenta. Es deixa durant uns minuts fins que s'observa algun canvi en el globus.
4. Es retira l'ampolla del recipient amb aigua calenta i s'introdueix en el que conté aigua freda. Observa què passa amb el globus.

QÜESTIONS

a) Escriu en el full d'anotacions què observes en cada pas.
b) Consulta el QR per acabar d'entendre què està passant.

Procediment Experimental

LLEI DE CHARLES

Nivell de dificultat:

1. S'infla un globus i es lliga
2. Es prepara un recipient amb aigua molt calenta i un altre amb aigua molt freda.
3. S'introdueix el globus en el recipient amb aigua calenta i s'observa què passa.
4. Es passa el globus al recipient amb aigua molt freda i s'observa què passa.

QÜESTIONS

a) Escriu en el full d'anotacions què observes en cada pas.
b) Consulta el QR per acabar d'entendre què està passant.

Procediment Experimental

LLEI DELS GASOS IDEALS (I)

Nivell de dificultat:

En aquest experiment es fan reaccionar l'àcid acètic (vinagre) i el bicarbonat per donar diòxid de carboni, un gas. Aquest gas es recull i es mesura el seu volum. Considerant pressió atmosfèrica (1 atm) i temperatura ambient (25 ºC), es podran calcular els mols de gas que s'han format.

La reacció que té lloc és la següent:

$$CH_3COOH + NaHCO_3 \longrightarrow CO_2 + H_2O + CH_3COONa$$

El pas més complicat és recollir el gas. Es recomana practicar el muntatge un parell de vegades abans de fer l'experiment.
Amb el QR podeu accedir a un vídeo on s'expliquen tots els passos a seguir.

Procediment Experimental

LLEI DELS GASOS IDEALS (II)

Nivell de dificultat:

1. Muntatge del sistema per recollir els gasos.
2. En un matràs Erlenmeyer s'introdueixen uns 15 mL de vinagre.
3. Es pren una petita quantitat de bicarbonat de sodi amb la punta de l'espàtula i s'introdueix a l'Erlenmeyer.
4. Ràpidament es tapa l'Erlenmeyer amb el tap de suro connectat al sistema per recollir el gas.

⚠ El pas de 3 a 4 s'ha de fer molt ràpid per evitar que s'escapi gas !!!

5. Es deixa reaccionar fins que ja no s'observa bombolleig dins la proveta.
6. S'anota el volum de gas recollit.

Procediment Experimental

LLEI DELS GASOS IDEALS (III)

Nivell de dificultat:

QÜESTIONS

a) Escriu en el full d'anotacions què observes en cada pas.
b) Calcula els mols de gas obtinguts.

Residus

En aquesta experiència no s'han utilitzat reactius que siguin nocius per la salut o el medi ambient.

Tots els residus generats poden anar per l'aigüera.

L'ampolla de plàstic i els globus es poden reutilitzar en aquesta mateixa experiència. En cas de llençar-ho, han d'anar al contenidor groc.

ECO-FRIENDLY

Qüestions Finals

1. Què li passa a una pilota de plàstic quan es deixa molta estona al sol? Justifica-ho a partir de la teoria cineticomolecular.

2. Per què es desinfla la pilota per la nit? Justifica-ho a partir de la teoria cineticomolecular.

3. Quina llei dels gasos s'aplica en aquests dos casos?

APPENDIX 2: MATERIALS AND REACTANTS DISTRIBUTION PER EXPERIMENT

Table 4. Reactants distribution per experiment.

REACTANTS	Gasos	Luminiscència	Cromatografia	Electròlisis	Indicadors	Equilibri	Cinètica	Solubilitat
Acetic acid (vinagre)	X				X	X		
Chlorohydric acid					X	X		X
Cobalt (II) nitrate hexahydrate						X		
Dishwasher soap							X	
Distilled water		X	X	X			X	X
Effervescent tablets							X	
Ethanol					X			
Food coloring (blue, red and yellow)			X					
Hydrogen peroxide							X	
Luminol		X						
M&M			X					
Manganese (IV) oxide							X	
Phenolphthalein					X			
Potassium bromide								X
Potassium hexacyanoferrate (III)		X					X	
Silver nitrate						X		X
Sodium bicarbonate	X					X		
Sodium chloride		X	X					X
Sodium hydroxide		X			X			
Sodium sulfate				X				
Turmeric or curry					X			

Table 5. Materials distribution per experiment.

MATERIALS	**Gasos**	**Luminiscència**	**Cromatografia**	**Electròlisis**	**Indicadors**	**Equilibri**	**Cinètica**	**Solubilitat**
6 V battery				X				
Balloons	X							
Beaker 100 mL		X		X	X		X	
Beaker 250 mL							X	
Beaker 500 mL		X	X	X				
Candle	X							
Chromatography paper			X					
Clips			X					
Cork stopper	X							
Crocodile clips				X				
Elbow pipe	X							
Electrodes				X				
Erlenmeyer flask 125 mL	X							
Filter paper					X			X
Funnel	X				X			X
Graduated cylinder 50 mL	X	X	X	X	X	X	X	X
Laboratory clock glass			X					
Lighter	X							
pH paper indicator					X			
Plastic bottle	X					X		
Plastic container 1L	X					X		
Plastic cups								
Scissors	X							
Screw caps								

APPENDIX 3: BUDGET BREAKDOWN

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Table 6. Budget breakdown of the reactants

Reactants	Kit content	Price	Cost for 1 kit(€)	Cost for 5 kits(€)	Cost for 10 kits (€)
Chlorohydric acid	60 mL	12,79€/L	12,79	12,79	12,79
Cobalt (II) nitrate hexahydrate	30 g	75,73€/250g	75,73	75,73	151,46
Effervescent tablets	6 u	3,65€/24u	3,65	3,65	7,30
Food coloring (blue, red and yellow)	3 color pack	17,90€	17,90	89,59	179,00
Luminol	5 g	91,54€/5g	91,54	457,70	915,40
Manganese (IV) oxide	30 g	58,82€/500g	58,82	58,82	58,82
Phenolphthalein	60 mL	4,36€/125mL	4,36	13,08	21,80
Potassium bromide	30 g	9,99€/100g	9,99	19,98	29,97
Potassium hexacyanoferrate (III)	30 g	71,98€/500g	71,98	71,98	71,98
Silver nitrate	60 mL	61,27€/L	61,27	61,27	61,27
Sodium bicarbonate	30 g	7,15€/500g	7,15	7,15	7,15
Sodium hydroxide	60 mL	17,40€/L	17,40	17,40	17,40
Sodium sulfate	30 g	11,43€/500g	11,43	11,43	11,43
		TOTAL	**444,01**	**900,48**	**1545,77**

Table 7. Budget breakdown of the materials.

Materials	Kit content	Price	Cost for 1 kit(€)	Cost for 5 kits(€)	Cost for 10 kits (€)
6 V battery	1	17,20€/u	17,20	86,00	172,00
60 mL reactant bottles	10	59,04€/127u	59,04	59,04	59,04
Balloons	2	1,27€/100u	1,27	1,27	1,27
Beaker 100 mL	2	0,80€/u	1,60	8,00	16,00
Beaker 250 mL	2	1,15€/u	2,30	11,50	23
Beaker 500 mL	3	1,55€/u	4,65	23,25	46,50
Chromatography paper	20 strips	44,53€/25sheets	44,53	44,53	44,53
Cork stopper	1	7,97€/32u	7,97	7,97	7,97
Crocodile clips	2	4,77€/10u	4,77	4,77	9,54
Dropper caps	4	15,65€/20u	15,65	15,65	31,30
Elbow pipe	1	3,08€/u	3,08	15,40	30,80
Electrodes	2	18,62€/100u	18,62	18,62	18,62
Erlenmeyer flask 125 mL	1	2,14€/u	2,14	10,70	21,40
Filter paper	4	5,31€/100u	5,31	5,31	5,31
Funnel	1	2,08€/u	2,08	10,40	20,80
Graduated cylinder 50 mL	1	1,57€/u	1,57	7,85	15,70
Laboratory clock glass	3	0,86€/u	2,58	12,90	25,80
pH paper indicator	1	7,15€/u	7,15	35,75	71,50
Screw caps	6	3,26€/20u	3,26	6,52	9,78
Silicone tube 50 cm	1	1,31€/u	1,31	6,55	13,10
Spatula	1	1,29€/u	1,29	6,45	12,90
Test tube holder	1	13,99€/u	13,99	69,95	139,90
Test tubes	4	2,20€/10u	2,20	4,40	8,80
Toolbox	1	10,80€/u	10,80	54	108
Waste containers	4	3,25€/u	13,00	65,00	130,00
Wood sticks	8	11,99€/100u	11,99	11,99	11,99
		TOTAL	**259,35**	**603,77**	**1055,55**

Table 8. Partial budget breakdown of the workforce with a salary of 40€/h .

WORKFORCE	Hours	Cost for 1 kit (€)	Cost for 5 kits (€)	Cost for 10 kits (€)
Teaching materials' development	56	2240,00	2240,00	2240,00
Materials and reactants search	4	160,00	160,00	160,00
Labeling	2	80,00	400,00	800,00
	TOTAL	**2480,00**	**2800,00**	**3200,00**

Table 9. Partial budget breakdown of the workforce

WORKFORCE	Hours/1 kit	Hours/5 kits	Hours/10 kits	Cost for 1 kit (€)	Cost for 5 kits (€)	Cost for 10 kits (€)
Reception and organitzation of the material	3	8	12	120,00	320,00	480
Kit assembly	4	12	18	160,00	480,00	720,00
	TOTAL			**280,00**	**800,00**	**1200,00**

Table 10. Total cost of the workforce.

	Cost for 1 kit (€)	Cost for 5 kits (€)	Cost for 10 kits (€)
Total cost of the workforce	**2760,00**	**3600,00**	**4400,00**

APPENDIX 4: SURVEY PROPOSAL

Valoració del ChemKit

Enquesta al professorat per valorar el ChemKit i fer propostes de millora.

1. Quines experiències heu realitzat

Seleccioneu totes les opcions que corresponguin.

- [ ] Els gasos
- [ ] La cromatografia
- [ ] L'electròlisi de l'aigua
- [ ] La cinètica de les reaccions químiques
- [ ] La solubilitat
- [ ] Els indicadors de pH
- [ ] La quimioluminiscència
- [ ] L'equilibri químic

2. Per què heu triat aquests experiments?

3. *Marqueu només un oval.*

- ( ) Opció 1

4. Valoreu de l'1 al 10 la identificació de cada element o material dins del ChemKit.

Marqueu només un oval.

	1	2	3	4	5	6	7	8	9	10	
Gens adequat	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Molt adequat

5. Valoreu de l'1 al 10 la robustesa i idoneïtat del material per a ús escolar.

Marqueu només un oval.

	1	2	3	4	5	6	7	8	9	10	
Gens adequat	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Molt adequat

6. Especifiqueu les incidències que hagueu pogut tenir amb el material.

____

7. Amb quin(s) nivell(s) d'ESO i/o batxillerat heu fet servir el Chemkit?

Seleccioneu totes les opcions que corresponguin.

- [ ] 2n ESO
- [ ] 3r ESO
- [ ] 4t ESO
- [ ] 1r batxillerat
- [ ] 2n batxillerat

8. Especifiqueu accions que permetrien millorar el material.

9. Quines experiències t'agradaria trobar en el kit en un futur?