Digital Simulation and experimental activities in Physics and Chemistry. Pilot study on the impact of the resource "Fusion and boiling points" with Level 7 pupils

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Abstract:
Technologies, which are suitably integrated and in harmony with the curriculum, are a source of renewal in education and pedagogical practices. The application of simulations is particularly beneficial to the teaching-learning process in Science. In this article, the development of a simulation called "Fusion and Boiling Points" is presented, which aims to provide pupils with the learning situations that will enable them to learn the concepts of Physics and Chemistry in Level 7, in a more meaningful way. A qualitative study was carried out, based on the observation of the pupils during the interviews. The didactic use of this simulation is additional to the practical and experimental component and never replaces it.

Keywords:
Education, Information and Communication Technology, Physics and Chemistry, Computer Simulation.

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INTRODUCTION

Nowadays, the world is confronted with an immensity of languages and semiotic codes in which the analogical paradigm has become dominated by the digital. By merely combining two digits, 0 (zero) and 1 (one), an infinite amount of information can be placed and circulate on the Internet. The digital world has transformed humanity and formed the information society. This change has awakened the need to make alterations to Man's knowledge. The Green Book for the information society in Portugal (Green Book, 1997) states, at a certain point: "Life in today's societies demands the ability of each and every one of us to capture, transmit and process data, disseminated in an increasingly global and easily accessible space, and transform it into information and pertinent knowledge that can make a number of evolutionary scenarios and trajectories intelligible in individual and collective experiences. The information society demands new knowledge and practices in addition to a commitment to permanent learning."

Hence, power has ceased to be linked to muscular strength, energy resources or material goods, as was the case in the industrial society, to belong to those holding more organised and better quality information.

The advent of the information society forces us to reflect on the educational act itself and the role of its more direct participants. If a society is influenced by communication issues in such a decisive manner, which is the case nowadays, all behaviour, particularly that which is more directly linked to learning situations, will inevitably experience changes.

The guarantee to provide relevant, quality education is, undoubtedly, the best response educational systems can give to the information society.

Learning is the main activity of individuals and organisations in a changing society; learning other ways of developing new competences, new processes for creating new products, learning and discovering new needs, learning and equating new problems and finding new answers, continuously investing in education (Adell, 1997; Salomon, 2002).

Schools have not remained indifferent to the amount of change society has undergone, having been "invaded" by Information and Communication Technology (ICT). However, in spite of all the technological progress we have witnessed, it is in pedagogical dynamics that the school has hindered innovation, due to its strong ties to tradition. The implementation of collective work and the creation of other ways of managing time, space and content are, therefore, made difficult. All these factors reinforce the idea that the school is outdated in terms of external space and time.

Proximity between schools and the information society and also, between schools and pupils who were born into and have grown up in the digital era (for whom the world makes no sense without technology) will depend on its ability to become the centre of the learning community and flexibility to provide everyone with entries and exits that are adapted to the new social reality.

In this context, the 21st century school creates new challenges for teachers who are faced with new tasks every day and have to be capable of making the school experience relevant to the information society.

The mass information of data bases which reaches pupils in a disorganised manner forces them to adopt a more critical attitude and to acquire skills in selecting and manipulating pertinent information. Here, the teacher has a crucial role as organiser, supervisor, mentor and learning facilitator, by directing and giving greater meaning to this information. Thus, the responsibility of the teacher is increased rather than reduced since he/she ceases to act within a well defined area limited to the knowledge acquired in his/her initial training.

Teachers, who like the pupils themselves, are also experiencing an integrated version of the school in the information society, are faced with the challenge of having to overcome the apparent dichotomy between traditional education and ICT based education and having to recreate ways of developing the broadest and most varied competences in their pupils.

So, in this article a brief reference has been made to the pedagogical advantages and limitations of ICT use in an educational context, and the use of computer simulations in the teaching of Physics and Chemistry is given particular attention. This is followed by a brief reflection on the importance and use of experimental work in the teaching of Science, moving on to a description of the simulation creation process entitled "Fusion and Boiling Points". We end with the pilot study involving Level 7 pupils, its results and conclusions as well as some proposals for future projects.

ICT IN SCHOOL: PEDAGOGICAL POTENTIALITIES AND LIMITATIONS

The inclusion of ICT in an educational framework is fundamental for a country's development through the broader education of its citizens and their ability to demonstrate flexibility and communication skills. Such education will enable them to become better integrated in a world that is constantly undergoing change.

Acknowledging all the didactic possibilities stemming from the use of curriculum integrated ICT for educational purposes means learning through it rather than learning about it. It involves harmoniously including it with the other components of this curriculum; it means using it as an important part of the aim to support a subject or content and not as an appendix or peripheral resource.

In this context, Decree-Laws no. 6 and 7/2001 of 18 January were published, with reference to the respective curricular reorganisation of Basic and Secondary Education. They focus on the use and integration of ICT in the classroom. Article 3 of Decree Law 6/2001, which specifies the main principles of the curriculum acknowledges the "(…) importance of a diversity of teaching methodologies and strategies and learning activities, particularly with recourse to information and communication technology".

By creating a technologically competent user, the school can contribute to preventing the possible social exclusion of the pupil while actively collaborating in his/her success in the information society.

The pedagogical practices that use curriculum integrated ICT in a planned and systematic way have a wide range of potentialities (Wild, 1996). One of the most well-known potentialities is that it helps the pupil to discover knowledge on his/her own: it is an active way of teaching, whereby the teacher occupies an intermediary position between the information and the pupils, pointing out paths and encouraging creativity, autonomy and critical thinking. There is a reflective and participatory relationship between the pupil and the surrounding world. The technologies encourage reflection (meta-cognition), the organisation of such thinking and cognitive and intellectual development, namely formal reasoning. The diversification of teaching-learning methodologies, the increase in student and teacher motivation, the volume of available information and the potential of interdisciplinarity are other advantages the pedagogical use of ICT can provide. ICT's ability to formulate hypotheses, test them, analyse results and reformulate concepts is equally acknowledged and is, therefore, in accordance with scientific knowledge. At the same time it enables simultaneous work with other geographically distant people, encourages the use of strict, highly important measures in Physics and Chemistry and the control of laboratory equipment (sensors and interfaces). The creation of micro-worlds is also another of ICT's pedagogical potentialities: it is able to simulate experiences which are too fast or slow in reality and which use dangerous materials or occur in conditions that are impossible to reproduce. The technologies are also good allies in the detection of pupil difficulties.

ICT's pedagogical potentialities are not yet being used to the full by teachers and pupils, given the fact that there are some limitations to their use. Some of these constraints form the barriers between the technological innovations that emerge naturally in schools and trigger the need for consciousness-raising actions. The school will have to realise that it is no longer the only source of knowledge transmission. On the other hand, the scarcity of high quality technical and pedagogical software, which implies the collaboration of teachers and programmers is also presented as a limitation to the use of technology. There are also other limitations which are related to the large number of pupils who, due to financial difficulties, do not have a computer, the lack of initial and continuous training for the use of technology and respective pedagogical benefit on the part of teachers, the lack of knowledge regarding the impact of ICT use in an educational context and the scarcity of time, which is indispensable to the learning of technology and preparation of classes. There are also other restrictions involving the inappropriate use of technological material considered to be pedagogically enriching, the absence of specific sites for all the content which encourages free navigation on the Internet which, without proper guidance, could become dispersed.

In a general way, it may be affirmed that in spite of these constraints, the integration of ICT in schools is quite a powerful auxiliary resource for innovating the teaching-learning process. Technology is a good excuse for change but nothing more, since renewal will always have to go beyond a machine!

DIGITAL RESOURCES FOR THE TEACHING OF PHYSICS AND CHEMISTRY — THE SPECIFIC CASE OF COMPUTER SIMULATIONS

In the teaching of Science, ICT takes on particular importance since its didactic potential is intrinsic, namely its usage for exploring aspects such as simulation, modelling, interactivity, movement, and three-dimensional perspective, among others (Cachapuz *et al.*, 2002).

In Physics and Chemistry computer usage has evolved considerably. In the context of our work, we have focused on the computer simulations which are programmes presenting a model of a real or imaginary system (Paiva & Morais, 2006).

Simulations constructed for educational purposes have evolved. As the software and hardware become more sophisticated, the simulations become more realistic with more options for the user to control the dynamics of the phenomenon shown on screen (Mintzes *et al.*, 1998). They make possible the manipulation of a diversity of experiences, namely complex, slow and even dangerous to reproduce in the classroom. The pupil can check the validity of his/her hypotheses in terms of the situations that emerge in the simulated environment, manipulate variables and verify alterations in the model's behaviour towards a variety of conditions.

Computer simulations can become an important accessory to direct contact with natural phenomena and experimental work, but should never replace them since it does not make sense to simulate a process that can be easily observed (Boyle, 1997).

The appropriately integrated and planned use of computer simulations brings is of some pedagogical benefit as these resources may arouse or increase the interest of the pupils, given the possibility of varying parameters and observing the effect of these variations in diverse situations and conditions, with the opportunity of reflecting and making new decisions. The simulations offer the pupil the possibility of developing hypotheses, testing them, analysing results and perfecting concepts. This way of using the computer in education is very practical for encouraging group work. The different groups can test different hypotheses and, thus, have more "real" contact with the problem. The use of computer simulations is coherent with the actual practice of scientific research which tends to use them more and more. The creation of an interactive environment to "learn by doing", which can be found in the simulations, enables the pupil to be more involved and have a more active participation in the creation of knowledge. Another great pedagogical advantage of computer simulations is the fact that they encourage interdisciplinarity, since the environment represented can be transdisciplinary.

Nevertheless, the use of computer simulations also presents difficulties, namely based on the fact that good computer simulations require great computer power and good graphic and sound resources, so as to make the situation –problem as realistic as possible. On the other hand, it is important to realise that the use of a simulation in itself does not create the best learning situation. The simulation should be viewed as a compliment to other teaching strategies. Notwithstanding, there is no guarantee that learning occurs and that knowledge can be applied to real life. Another limitation which must be taken into account is the possibility that the pupil will form a distorted vision in relation to the world, for example, being led to believe that the real world can be simplified and controlled in the same way as the simulation programs. Therefore,, conditions have to be created for the pupil to make the transition between simulation and the phenomenon in the real world. This transition does not occur automatically and requires some level of preparatory work.

EXPERIMENTAL WORK IN THE TEACHING OF PHYSICS AND CHEMISTRY – DATA AND REFLECTIONS

Experimental work is fundamental and essential to the learning of experimental sciences such as Physics and Chemistry.

Oliveira (1999) explains that the discussion of experimental work refers to "research in which the pupils can develop meaningful experiments using a variety of resources through which they can construct concept meanings within learning communities, which are accepted by the scientific community."

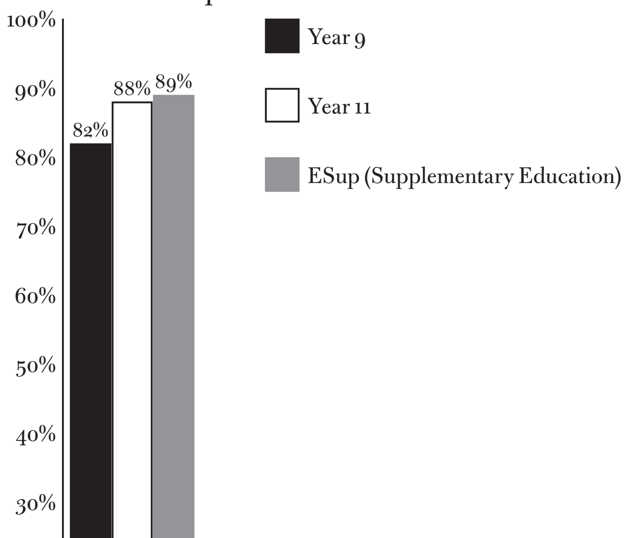
There are a number of important objectives to be accomplished through experimental work (Gunstone, 1991; Sweeney & Paradis, 2004). Some of the more important ones involve instilling in the pupils skills and attitudes associated with problem-solving in Science which are transferable to daily life, such as: a creative mind, the formulation of hypotheses, observation, decision-making, a critical mind, curiosity, responsibility, autonomy and persistence. Familiarising pupils with the theories, nature and methodology of Science and also with the Science-Technology-Society-Environment (STSE) relationship, in addition to raising the alternative conceptions of the pupil and stimulating cognitive conflict with a view to his/her conceptual change, are the aims of such experimental work. Amongst the desired aims and competences, experimental work has other aims to develop in the pupil: a taste for science in general and for the subject and/or content in particular, as well as psychomotor skills to ensure the efficient accomplishment and technical rigour of the activities performed; to provide the pupil with experience of the facts and natural phenomena and to encourage him/her to intervene consciously in the solving of ecological/environmental problems, while simultaneously stimulating his/her socialisation (participation, communication, cooperation, respect, among others) with a view to better social integration are also important aims in the performance of experimental work.

As already mentioned, the performance of experimental work is of utmost importance. The pupils are the first to acknowledge this importance and to show pleasure in carrying out the tasks.

This can be verified by observing the following data provided by Martins *et al.* (2002, 2005).

Through the analysis of Graph 1, we can see that a significant majority of pupils (82% of Level 9 pupils) enjoy accomplishing experimental activities in Physics and Chemistry.

Graph 1 — Pleasure in accomplishing experimental activities



Source: Martins *et al.*, 2002, p. 105.

According to Martins *et al.* (2005), if we compare the different percentages between Physics and Chemistry, we can affirm that the pupils prefer experimental activities in Chemistry since: they motivate the pupils towards scientific subjects; they make the lessons more enjoyable and interesting and develop skills in handling laboratory equipment.

However, according to Martins *et al.* (2002), unfortunately only a minority, around 27% of teachers regularly use experimental activities in Physics and Chemistry, spending, on average, less than 20 hours per academic year on them. Carrying out experimental work is not common practice among Physics and Chemistry teachers. In general terms, it may be said that the Basic Education teachers perform more activities related to Physics than to Chemistry and that most of these experiments are essentially the most classic.

According to Table 1, the most practised set of experiments may be broken down as follows: "Processes of separating mixtures"; "Acid –base reactions; indicators; pH scale". In the set of less performed activities, the "Determination of fusion and solidification points "may be found.

The practical and experimental activities used are primarily closed and geared towards the verification of laws, phenomena and theories that focus little on the formulation and verification of hypotheses in open problem-solving.

Table 1 — Experimental activities accomplished in level 8

CHEMISTRY	%
Separation of mixture processes	99
Safety Rules in the Cheminstry Laboratory	98
Acid-base reactions; indicators; pH scale	99
Label analysis of several chemical products	96
Cromatography	96
Study of several chemical reactions	93
Density determination of substances	90
Analysis of homogeneous and heterogeneous mixtures	86
Lavoisier's Law	87
Separation of pure substances	83
Energy from chemical, exothermic, endothermic and athermic reactions	82
Factors that affect the speed of a reaction	79
Determination of fusion and solidification points	48

Source: Martins *et al.*, 2002, p. 69.

When there are more than 22 pupils, it is common in schools to split the class into two so that the teachers can include laboratory and experimental activities. However, according to Martins *et al.* (2002), it is known that teachers used these teaching periods to reinforce a more focused approach on the systematisation and solving of exercises and less on laboratory practice and the development of competences. Only 26 % of the teachers in the survey use these periods to carry out experiments always or almost always, while 51% frequently use them to solve exercises (Table 2).

	Performance of experimental work	Content revision	Teaching new content	Exercice solving
Never or rarely	2	27	42	3
Sometimes	37	55	44	35
Often	36	14	11	51
Always or almost always	26	4	4	11

Source: Martins *et al.*, 2002, p. 130.

Table 2 — Way of occupying lesson time in practical lessons

CREATION OF THE SIMULATION "FUSION AND BOILING POINTS"

Program Content

The Curricular Guidelines for Physical and Natural Sciences in the 3rd Cycle point to the teaching of cycle-based content rather than year-based, so as to provide pupils with a set of essential competences which they should acquire up to the end of this cycle through the study of four main themes: Earth in Space; Earth in Transformation; Sustainability of the Earth and Living Better on the Earth.

The theme Earth in Transformation was chosen due to the fact that it introduces the study of Chemistry in Basic Education. In accordance with the National Curriculum of Basic Education – Essential Competences with this theme – Earth in Transformation *:* "(…) the aim is that pupils acquire knowledge of Earth-related factors and phenomena".

Within the context of the Master's degree in Multimedia Education offered by the Faculty of Science of the University of Porto, the aim was to develop a set of digital resources with a view to making this initial contact with Chemistry an enriching and motivating experience for pupils, so as to contribute towards their enjoyment of the subject. In addition, it was also the aim to provide them with learning experiences that would lead them to acquire more knowledge, to learn better and in a more meaningful way.

The digital resources developed were then used by a publisher of school manuals and are currently part of a pioneer project offering an integral combination of a digital manual with multiple multimedia resources which complement and specify content throughout the manual– Manual Multimédia 7CFQ (Fiolhais *et al.*, 2006).

Of all the digital resources that were developed, we will focus on the simulation: "Fusion and Boiling Points".

Technical and Visual aspects considered in the creation of the "Fusion and Boiling Points" simulation

The choice of programs and/or computer tools used in the creation of the simulation "Fusion and Boiling points" was very specific, based on the final result that was hoped to be achieved, as well as our main aim: to motivate pupils to study Chemistry. So, some of the programs used for its creation were: the *Macromedia FreeHand*, *Adobe Photoshop*, *Macromedia Flash*, *Adobe Premíere* and *Pro-Tools – HD7*.

The visual appearance and creation of a pleasant, friendly atmosphere for use can, to a certain extent, contribute to the motivation of the pupil in his/her use of the resource. Thus, several aspects that justify our colour, text, letter type, screen space, interface and animation options have been taken into account.

Due to the age group of the pupils who were the target of the simulation, short, easily readable texts were selected to help in the understanding of the content while also preventing demotivation and boredom. Some contextual and operational indications are presented on the various simulation screens (Roerden, 1997).

The following are print screens of the simulation screens "Fusion and Boiling Points" (Figure 1).

Figure 1. Several screens of the simulation "Fusion and boiling points".[1]

PILOT STUDY OF THE SIMULATION "FUSION AND BOILING POINTS" WITH LEVEL 7 PUPILS

Description of the study

The sample used in the study was a Level 7 class from the school *Escola EB 2,3 de Maria Lamas* – Porto, in the academic year 2005/2006. The class was made up of 15 boys and 6 girls of an average age of 12.

The 45 minute lesson was planned in which the computer simulation was used by the pupils and a support scheme was set up for its use (Figure 2). This scheme aims to narrow the gap between the educational software pieces and the learning aims that are sought to be developed (Morais, 2006). (The *roteiro de exploração* [type of Webquest activity] is available at URL http://www.jcpaiva.net/content.php?d=curriculum/12).

It was a qualitative, introductory study based primarily on the close observation of pupils in their use of the software and the accomplishment of interviews. The following are some of the results of this study.

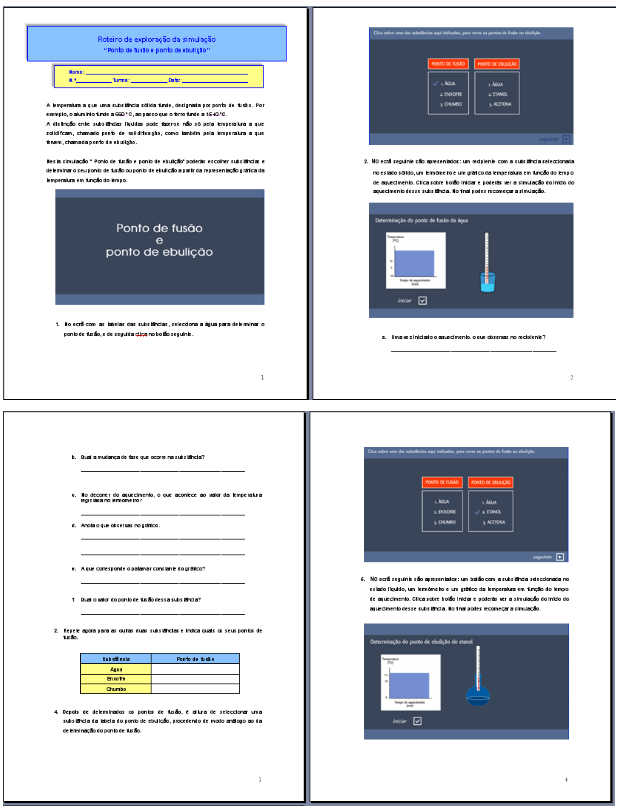


Figure 2. *Roteiro de exploração* for the simulation "Fusion and boiling points".[2]

Analysis of results

The impact of applying the simulation "Fusion and Boiling Points" to the teacher-learning process was evaluated by analysing responses to the questions in the *roteiro de exploração*, analysing the observations made and interviews carried out. The analysis of the results is based on a qualitative approach (Morais, 2006).

Having the lesson in the computer room proved to be a source of motivation for pupils. The use of the simulation by the pupils was initially very impulsive, without sufficient attention to the instructions for use table (which had previously been explained to pupils). Perhaps the pupils' increased interest was due to the fact that they considered the simulation appealing as they were allowed to choose the substance, select whether they wanted to observe its fusion or boiling, as well as watch the construction of a graph, observe the temperature in real time as the process of heating occurred. As soon as they had internalised the *roteiro de exploração*, the lesson ran smoothly, without help being requested from the teacher.

The questions in the *roteiro de exploração* were answered without difficulty. In general, most pupils came to the conclusion that the fusion and boiling point are physical properties which make the identification of a substance possible and that the constant level in the graph corresponds to the temperature at which a pure given substance melts or enters the boiling stage.

There was some disorder in the correction of the questions since the enthusiasm and desire to participate was such that the pupils had to be reprimanded and asked not to forget the rules for organised participation, by raising a hand before speaking.

The pupils claim to have enjoyed using the simulation "Fusion and Boiling points". They refer to particularly having liked the graphs and thermometer; they learned how to read a graph better; the fact that they assimilated concepts linked to the simulation provided them with more significant meanings.

After using the simulation, all the pupils acknowledged the advantage of having the *roteiro de exploração* to hand, saying that: they know what the aim of the task is; it explains the main functionalities of the digital resource being used and favours commitment in the search for the correct answers; it prevents distraction towards less relevant aspects of the activity; it hinders indiscriminate and compulsive clicks; it enables one to reach a conclusion; they learn in a more meaningful way and make the most of the time allowed.

The aspects considered by pupils to be positive in the study of Chemistry using digital resources are: it is less difficult to learn; they understand the content more fully (since the resources can be seen and used again) and the use of images and audio helped them in their understanding and led them to be more attentive. Furthermore, the pupils feel that the teachers should use digital resources more frequently in their teaching practice. According to the pupils, the reasons why this does not happen are due to: a lack of ideas or possibility of using them; the teachers view the "blackboard and chalk" as more efficient means and are what teachers are more accustomed to using.

FINAL CONCLUSIONS AND PROPOSALS FOR FUTURE PROJECTS

We are convinced that the creation of this simulation can contribute to furthering understanding of the fusion and boiling concepts as well as complimenting the experimental determination of these two physical properties, since the "Determination of the fusion and boiling points" is in the group of less performed experiments in Chemistry (see Table 1, Section 4).

The use of computer simulations, in general, brings benefits to the teaching-learning process and triggers off very positive reactions in the pupils, namely: "this simulation is great, you can see the graph as the temperature increases"; "I never understood anything about graphs, but these ones are easy because we can see what happens to the temperature while we watch the computer drawing the graph."

The pupils enjoyed using the digital resources, however, this may also be due to an extra motivation factor – novelty. They all acknowledged the pedagogical benefit and advantage of the *roteiro de exploração* and, above all, they acknowledge having learned more and in a more effective way.

Owing to the limitations in the conclusions and generalisations (threats to internal and external validity) of the study, the results obtained can not be considered anything more than a simple, positive indicator in favour of the use of digital resources by pupils. Nevertheless, there has to be a change in the mentalities, attitudes and perspectives of the various participants in the educational process if this is to become an increasingly more common reality in our schools.

Following what has been done we intend to carry out a new testing phase of a constructed prototype in the near future, to participate directly with the teachers with a view to improving the developed resources and producing new digital resources for higher education levels. We also intend to evaluate their impact on the pupils in a systematic way.

All suggestions are welcome.

Endnotes

1. Figure 1
Fusion Point and Boiling Point

In this simulation you can choose three substances to determine fusion point and another three to determine boiling point

Click on one of the substances below to see boiling or fusion point

Fusion
1. Water
2. Sulphur
3. Lead

Boiling
1. Water
2. Ethanol (Alcohol)
3. Acetone

Determination of the boiling point of water
Temperature
Heating time (mins)
Restart >
What is the boling point of water?
Correct

Determination of the fusion point of lead
Temperature
Heating time (mins)
Restart
What is the fusion point of lead?
Correct

2. Figure 2
Roteiro de Exploração for the simulation "Fusion and Boiling Points"
Name _______
No. _____ Class _____ Date _____

The temperature at which a solid substance melts, called the fusion point. For example, aluminium melts at 600°C, while iron melts at 1540°C.

The distinction between liquid substances can be made not only by the temperature at which they solidify, but also the temperature at which they boil, called boiling point.

In this simulation "Fusion and boiling Points", you can choose substances and determine their fusion or boiling point from the graph reading of the temperature according to time.

Fusion and Boiling Points
1. On the screen with the table of substances, choose water to determine the fusion point and then click on the following button.

Click on one of the substances below and see their fusion and boiling points
Fusion Point
1. Water
2. Sulphur
3. Lead

Boiling Point
1. Water
2. Ethanol (Alcohol)
3. Acetone

2. A container with the selected substance in its solid state, a thermometer and temperature graph based on heating time are shown on the following screen. Click on the start button and you will be able to see the simulation from the beginning of the heating of the substance. At the end you can restart the simulation.

Determination of the fusion point of water

Temperature
Heating time (mins)
Start

a. Once the heating has started, what do you see in the container?
b. What change of stage occurs in the substance?
c. As the heating takes place, what happens to the temperature on the thermometer?
d. Make a note of what you see on the graph.
e. What does the constant level of the graph correspond to?
f. What is the fusion point figure of this substance?

2. Repeat the same for the other two substances and indicate their fusion points.

Substance	Fusion Point
Water	
Sulphur	
Lead	

4. After determining the fusion points, it is time to select a substance from the boiling point table and to proceed in the same way to determine the fusion point.

Click on one of the substances below and see their fusion and boiling points

Fusion Point
4. Water
5. Sulphur
6. Lead

Boiling Point
4. Water
5. Ethanol (Alcohol)
6. Acetone

6. A flask with the selected substance in its liquid state, a thermometer and temperature graph based on heating time are shown on the following screen. Click on the start button and you will be able to see the simulation from the beginning of the heating of the substance. At the end you can restart the simulation.

Determination of the boiling point of ethanol.
Temperature
Heating time (mins)
Start

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