Erasmus+

Inquiry-Based Learning in Remote Setting

Editors **Dagmara Sokołowska**
Mojca Čepič

Authors: **Dagmara Sokołowska**
Mojca Čepič
Eilish McLouglin
James Lovatt
Reinout Putman
Ana Gostinčar Blagotinšek
Paul Grimes
Jan de Lange

This book is an output of the Remote Inquiries in Science Education (RISE) project, which was funded by Erasmus + KA2, project number 2020-1-SI01-KA226-SCH-093576

Remote Inquiry in Science Education

RISE

To cite: Sokołowska, D., Čepič, M., McLoughlin, E., Lovatt, J., Putman, R., Blagotinsek, A., Grimes, P., de Lange, J. (2023). *Inquiry-Based Learning in Remote Setting* (D. Sokołowska, M. Čepič, Eds.). Publisher. DOI.

Table of contents

Introduction

Nowadays, more than ever, humans face rapid and massive changes we already experience and can anticipate in the future - both in our lives and globally. Currently, in education, we are confronted with the situation in which we need to prepare learners for challenges in their lives and careers that are not even yet defined. Such a conjuncture puts on teachers a great responsibility not only for the development of students’ competencies tailored to the XXI century but also for teachers’ own continuous professional development since, nowadays, education more than ever depends on the adaptable and responsive attitude of teachers.

When entering the education system, children are still curious and motivated. However, most of them lose their interest in learning quite soon. Thus, we need to support and maintain the curiosity and inquisitive attitude of young children in order to extend it over their entire lives and thus promote in them a life-long-learning attitude. The modern world increasingly depends on exact, natural, and technical sciences. Therefore there is a growing need to attract people who would associate their professional careers with developing these disciplines. Everyday science and mathematics literacy is required for equal accessibility to achievements of civilization and sustainable development of all societies. Since these are areas closely related to experience and practical work, special emphasis should be put on developing practical research skills, basing teaching on experiments and specific references to everyday life in motivating and teaching them. Following a recommendation in the document called Rocard's Report[1] (2007), the best teaching strategy in this area is the inquiry-based learning method.

Inquiry-based learning approach has been researched and developed for more than 50 years now. Since 2007, it has been broadly disseminated through many EU projects for education (e.g., *Fibonacci, Establish, SAILS, Irresistible*, etc.). In the period 2017 – 2020, our group, composed of partners from Slovenia, Belgium, Ireland, and Poland, participated in the 3DIPhE[2] project focused on the introduction of an inquisitive way of thinking about science education to teachers using inquiry-based learning method in their science classes. Among others, we prepared a four-volume e-book[3] providing teachers with ready-to-use IBL units, guidelines for practitioner inquiry – evidence-based teachers’ reflection on their practice, tools for building professional learning communities, and the educational design research method for teacher professional learning. During the last six months of the 3DIPhE project, we faced yet another sudden change in the world – the COVID-19 pandemic, which turned upside-down the traditional thinking about education and raised an urgent need to support teachers in remote conditions.

This book is a result of two years of work to empower teachers to use digital tools and applications and to maintain an inquiry-based learning approach in their science classes, despite the lack of personal contact with students, the inability to provide in-person guidance of learners, and the lack of lab equipment for students staying at home. We propose a set of remote inquiry-based units in physics

---

[1] Rocard M. (Chair) (2007), Science Education NOW: A Renewed Pedagogy for the Future of Europe. Luxembourg: Office for Official Publications of the European Communities, 2007. Retrieved from: http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf

[2] 3DIPhE project, Three Dimensions of Inquiry in Physics Education, funded under ERASMUS+ KA2, grant agreement 2017-1-SI01-KA201-035523

[3] 3DIPhE e-book, https://www.3diphe.si/e-book/

and chemistry adapted to remote settings but also suitable for hybrid or in-person teaching. They were designed from scratch for the RISE project or adapted based on the materials from EU projects in which RISE partners got involved in the past.

The need for instant teacher training in methods suitable for remote classes emerged during the COVID-19 pandemic. However, the remote teaching format remains essential and valid, not only for this specific occasion. Teachers should develop their teaching skills in teaching the IBL-R (inquiry-based learning in remote settings) during their pre-service teacher education to be well prepared for unexpected situations and quickly adapt their lessons in case of absence caused by illness, lab classes in a homeschooling format, or online education related to the refugee migration, to mention only a few. However, despite our last few years of experience, such training is still not a standard. In addition, the multitude of in-service teachers who could never have had a chance to encounter such an issue in the past (including the lack of such preparation for their profession) need urgent and constant support to prepare to face future remote learning instances.

Inquiry-based Learning

Inquiry term was used for the first time in education, most probably by John Dewey in his early twentieth-century works. Still, Schwab[4] and Bruner[5] finally arose the concept of inquiry-based teaching in the early 1960s. It originates from the ideas of the founders of constructivism (J. Piaget, L. Vygotsky), a theory in education that recognizes learning as done by students who "construct" knowledge from their experience. Over the decades, the Inquiry-based Learning (IBL) approach evolved mostly in science education, and in 2007, Rocard's Report recommended it[6] as the best way to teach science subjects.

In 2020, as the result of the 3DIPhE project, we proposed an elaborate description of Inquiry-based Learning as *an active learning method in which students, to develop knowledge or find solutions (…), follow a scientific method used by researchers in science studies*[7]. The concept of the IBL is founded on the inquiry cycle (fig. 1), in which the learners are actively involved as it encourages asking inquiry questions, exploring scientific issues, drawing conclusions about phenomena in nature, and sharing ideas with others.

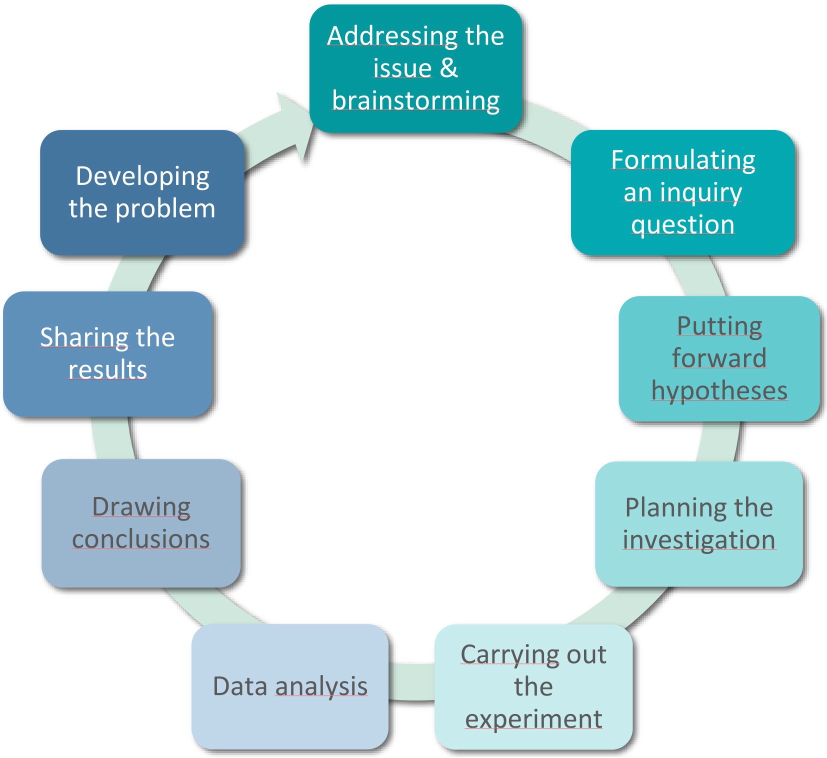


Fig. 1. Inquiry cycle

---

[4] J.J. Schwab (1960), *Inquiry, the science teacher, and the educator*, The School Review, 68(2), 176 - 195

[5] J.S. Bruner, (1961). *The Process of Education.* Harvard University Press, Cambridge Massachusetts, London England (p.14)

[6] Rocard M. (Chair) (2007), Science Education NOW: A Renewed Pedagogy for the Future of Europe. Luxembourg: Office for Official Publications of the European Communities, 2007. Retrieved from: http://ec.europa.eu/research/science-society/ document_library/pdf_06/report-rocard-on-science-education_en.pdf

[7] Sokołowska, D. (2020) Inquiry-based learning to enhance teaching (e-book), M. Čepič and D. Sokołowska (Eds.), University of Ljubljana, Faculty of Education, available at https://archive3diphe.splet.arnes.si/files/2021/01/3D_VOLUME1.pdf

Inquiry-based learning is an active learning method inherently based on collaborative work in groups that the teacher or students themselves form. The division into groups usually occurs after the inquiry cycle first or second step.

In the abovementioned approach, the inquiry learning cycle consists of nine steps.

1. **Addressing the issue** usually begins with **brainstorming** around an issue formulated at the beginning of this first stage. This is the phase of communication of associations, examples from life, as well as reference to existing knowledge. If the teacher decides not to disclose the chosen topic just from the beginning, then at this stage, s/he guides the students about the classes, using a question-interwoven story, to which s/he expects spontaneous student responses resulting from their life experiences.

   This stage is essential for three reasons. First of all, it is supposed to introduce two critical factors motivating students to continue working - to stimulate their curiosity and, at the same time, embed the issue itself in the context they are familiar with. Secondly, it is a moment when all learners can speak spontaneously, including those generally perceived as low achievers (based on the content-knowledge-based tests). Thirdly, this is the phase in which the teachers learn the level of their students, thanks to which they can adequately select elements of the further process - e.g., by avoiding proposing experiments whose result is already known to learners or diversifying experiments due to different level of knowledge and experience of learners in the selected topic. So, for the teacher, this is the moment for reflection and the last moment for adjusting the subsequent process.

   The brainstorming generally flows as a class discussion. It can be based on various clips, like intriguing photos, a short video, a simple experiment conducted by the teacher or students, or a storyline initiated by the teacher and developed through the participation of all students.

   It is recommended that the brainstorming refers to the topic of the IBL only indirectly, especially at the beginning, so as not to reveal the aim of the lesson too early but rather allow the students to get to it through vivid discussion.

2. **Formulating an inquiry question** is asking one or a series of questions related to the issue selected in the first point. This is where the topic narrows down and becomes more specific. The question may be qualitative or quantitative, but in principle, it should be structured so that it cannot be answered directly: “yes” or “no.” It should also be formulated so that the answer can be obtained as a result of a study conducted in specific conditions created during classes, i.e., taking into account class time, availability of materials, classroom conditions, and student safety. Usually, the question related to trends, the extent of influence of one (independent) variable on another (dependent) variable. Teachers and students should remember that the question must be formulated so that a fair test should be applicable to answer it.

3. **Putting forward hypotheses** on the outcomes of the planned investigation usually comes before or after raising inquiry questions and takes the form of a vivid discussion among students. Hypotheses formulated by students are based on their prior knowledge, context, and experience. They bring the joint reflection before performing the experiment based on reasoning and intuition, which are later confronted with the experiment's objective results.

4. **Planning the investigation** involves carefully considering the materials and equipment needed to conduct the experiment to answer the inquiry question and confront the hypothesis. Research groups of students also come to a conclusion about the sequence of actions and measurements they are going to take. At this stage, they also divide the work among themselves to avoid chaos and think about the safety conditions of the work they will do.
5. The first four stages finish the preparatory phase of the inquiry. **Carrying out the experiment** is the middle step of the cycle, the moment of *wresting scientific principles and laws from nature*[8]. Students conduct the experiment and record their experimental data (measurements or observations), handling safety issues with the greatest possible accuracy. They roughly check the data and decide if any part of the experiment needs repetition or any additional measurement should be taken. If the experiment does not work, students need to redesign their plan, returning to stage 4.

6. After completing all experiment steps, the final phase of the inquiry cycle begins. Students organize their notes and **analyze the collected data**. They need to employ knowledge and skills in data analysis and visual representation of data.

7. Based on the data analysis, students **draw conclusions**, trying to answer an inquiry question, and confront the objective results with the hypotheses they put forward in the preparatory part.

8. **Sharing the results** among the groups is a crucial social moment when students develop critical thinking and a respectful attitude towards others' work. It is the moment to compare the procedures and the outcomes and broaden learning by getting the solutions that come from the outside of the box of their own thinking, thus developing creativity. Sharing the results also allows the development of communication skills in students.

9. The last stage of the inquiry cycle opens the door to an extended inquiry on what was just done or to a new topic related to this inquiry.

The inquiry cycle of learning can be implemented in the classroom at three distinguishable levels (Fig. 2): structured inquiry, guided inquiry, and open inquiry, the order representing the increase of students' independence in the responsibility for their learning. In all levels of inquiry, the teacher initiates the brainstorming and conducts the class through it to the main topic of the lesson. In structured inquiry, the teacher poses also an inquiry question, and students get some independence in planning, carrying out the investigation, and data analysis. In guided inquiry, students get the opportunity to formulate the inquiry question in groups, put forward hypotheses, and continue working in groups over the inquiry cycle until the presentation of their results; the teacher can make

---

[8] J. Dewey (1920), *Reconstruction in Philosophy* in *The Middle Works*, 1899-1924, vol. 12: 1920.

general conclusions and summarize the lesson. In open inquiry, students are independent in their groups from the very beginning. The teacher can initiate a broad issue for investigation. However, the choice of the inquiry topic can also be left solely to students.

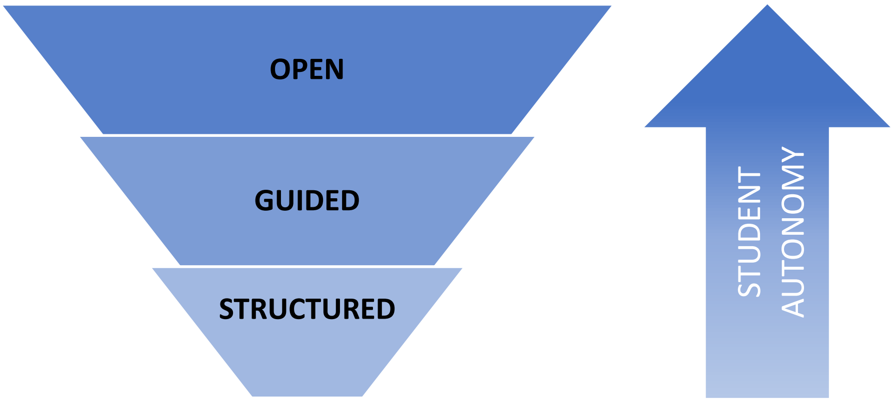


Fig. 2. Levels of inquiry

More about the aspects of Inquiry-based Learning, the condition of its implementation, the effectiveness of the method, and the assessment of learning by inquiry can be found in 3DIPhE vol. 1[9].

Remote IBL

Inquiry-based Learning conducted in a remote setting needs special attention to a few aspects. First, working in groups and smooth communication within and between groups, an inherent feature of the IBL and the pillar of the method should be ensured. Secondly, teaching IBL remotely requires more focus on the materials and tools used during the investigations. The teacher must revise existing IBL modules to replace school laboratory equipment unavailable in the remote setting with everyday materials and tools available at home. Third, the tools for communication and the exchange of materials in the remote classes should be carefully chosen to get the best possible quality of joint conversation, fluency of material circulation, and the quality of the online material produced by students during the remote classes.

Getting online

The remote setting demands from teachers, in addition to the standard IBL lesson preparation, excellent preparation of the digital tools for securing a stable internet connection, checking all electronic devices, and getting familiar with the functionalities of platforms, programs, and apps needed for the lesson. Since digital tools are the only connection between the teacher and the students, as well as among the students, easy and undisturbed use of them is a prior condition of any remote lesson.

---

[9] Sokołowska, D. (2020) Inquiry-based learning to enhance teaching (e-book), M. Čepič and D. Sokołowska (Eds.), University of Ljubljana, Faculty of Education, available at https://archive3diphe.splet.arnes.si/files/2021/01/3D_VOLUME1.pdf

Grouping

Working in groups is an indispensable feature of the IBL lesson, so it must also be maintained in the remote setting. Various strategies for selecting groups, valid in on-site classes, are also suitable for online activities. Depending on the general situation in the class (for example, student age, sympathies or animosities, student ability level, students with special needs), pupils can be divided into single-gender groups or mixed-gender groups, single or mixed-ability groups, groups of three or four, or even pairs, etc. The teacher can also anticipate the self-selection of group members. If the remote learning situation is prolonged, it can change without notice due to the lack of personal contact among students and between the class and the teacher, so special attention is needed to catch all its subtle indicators.

Working in groups requires isolated space for teams of students working together. Such conditions can be secured by choosing the right communication platform equipped with the *breakout rooms* facility, for example, *Teams, ZOOM, Google Meet,* etc.

Teachers can monitor the teamwork two-fold – by visiting the breakout rooms and by inspecting the documentation prepared by teams in specialized collaborative tools (see below)

Brainstorming

In the section *Inquiry-based Learning,* we described the benefits of starting the IBL with Brainstorming. In a remote setting, the initial involvement of students is even more critical for maintaining their motivation and engagement in the inquiry lesson. The teacher can select one of the formats mentioned above to make it effective, similar to on-site lessons. However, special attention should be paid to the actual presence of the students in the brainstorming stage of the lesson; it is recommended that all students have their cameras and microphones on. If such conditions are challenging to hold, students can be divided into smaller groups with the task of getting ready as a team for general discussion or preparing a brainstorming for the other group (similar to the activity described in the O2 Coursebook)[10].

Formulating an inquiry question and putting forward hypotheses

In the remote setting, students are stuck by the computer, usually sitting at the table, so their natural motor activity is hindered. This can be slightly restored by the dynamics scenario of moving around to breakout rooms and back to the main room, preferably in different group configurations at the beginning of the lesson. The division into final working teams can be slightly postponed, particularly in structured inquiry or guided inquiry lessons. Students can develop inquiry questions and put forward hypotheses moving forth and back to various breakout rooms. If the teacher wants students to work in the same teams starting just after the brainstorming, students can be given additional initial tasks, being called from their team breakout rooms forth and back to enhance the lesson dynamic.

At this stage, it may be helpful for teams to take joint notes of their discussions, so the teacher should invite them to a digital tool for note-taking, like *OneNote* or *Google Docs*. Suppose the teacher wants to monitor the engagement of teams and the progress of recording the discussion. In that case, s/he may propose the use of specialized collaborative tools (e.g., *Jamboard, Padlet, FigJam, LucidPark, Miro,*

---

[10] McLoughlin, E., Lovatt, J., Grimes, P., Cepic, M., de Lange, J., Blagotinsek, A., Putman, R., Sokolowska, D. (2023). *Supporting science teachers in the use of Inquiry Based Learning - A hybrid approach for teacher professional learning* (E. McLoughlin, J. Lovatt, P. Grimes, Eds.), Appendix A2

Canva Whiteboard, Mural) offering real-time collaboration and some of them – also easy supervision of students' work.

Planning the investigation

During online classes, it is essential that students write down their ideas and decisions since, during the remote investigation, the interaction between students and the teacher is limited. Thus, it is recommended to use collaborative tools (see the previous paragraph).

Carrying out the experiment

During online classes, students prepare the inquiry in teams, but they conduct the real investigation alone. It may be advisable if the teacher encourages them to divide the investigation into smaller parts, which can be carried out by group members, making them all responsible for the team's final.
Again, students from one team should take joint notes using the digital tool accessible to all of them in real time (see two previous subsections). In some IBL units, it is required to upload online photos as the results of observations or the evidence of carrying out the experiment. For that, digital File Management Systems (e.g., *Google Drive, SharePoint, Dropbox*) can be utilized, as well as fast communication tools like *WhatsUp* or *Signal*, which later on allow for quick downloading and smooth presentation of the results by students or the teacher (for all groups) in the main room.

Data analysis

Data recording during the investigation can be combined, elaborated, and visualized using digital data analysis tools like *Excell, Origin,* etc. It should be done in a breakout room to allow students for discussion during the analysis.

Drawing conclusions

Students need to work in teams in the breakout rooms to draw conclusions in the remote setting. Whenever the conclusions are formulated, teams prepare posters or presentations of the results using digital presentation tools like *PowerPoint, Canva, Prezi*, etc.

Sharing the results

Since in the remote setting, students work all the time using their computers, recording their work at most of the stages of the IBL cycle, sharing the results with other groups may become even more accessible than in an on-site setting. They present the IBL outcomes by sharing the screen in one of the communication platforms (*Teams, ZOOM, Google Meet*).

Securing the class dynamics

Keeping students' attention and motivation for the IBL activity may become more problematic in remote than in on-site settings. Thus, activities should be divided into smaller tasks, with planning more moving between breakout rooms and the main room and delivering small portions of any outcomes (team discussion notes, investigation recordings, etc.). If necessary, the teacher should plan additional warming-up activities and active brain breaks in advance to keep a vivid class dynamics.

IBL-R units

Introduction

In this section, we present 16 IBL-R units for the IBL science classes and 1, exclusively for the teacher training, adjusted to the remote setting, which can also be implemented in classes on-site. The modules contain hints about the equipment, materials, and specifics of the organization of the online classes. The units are divided into sections providing detailed information, as indicated in Table 1.

Table 1. Sections of the IBL units

Section	Information
Title page	**The title of the module, the names of the authors, and the level of inquiry.**
Introduction • Curriculum topics • IBL level • Age of students	**A short introduction contains the aims of the module** This subsection lists the curriculum topics to which the unit can be related. The IBL levels of particular parts of the IBL module are detailed. The age of the students the unit is meant for is given in detail.
Practicalities • Materials • ICT component • Grouping • Setting	**Practicalities contain details for the preparation of the unit implementation.** The list of equipment and materials is provided for each part of the unit. Specific ICT tools (applications, equipment) used by students are listed. Grouping format for on-site and remote classes is advised. Recommendation for onsite space arrangement and online communication tools.
IBL unit	**The IBL unit is divided into parts, indicating the time required to complete each.** Detailed information about the course of particular parts and their specific conditions is provided. In some cases, the exemplary student worksheets are included. Photos exemplifying the implementation of the module are attached.
Physics/chemistry behind	**This section contains an explanation of the phenomena experienced in the module.**
Appendix	**Appendixes provide additional instruction.**

During the RISE project, we designed or adapted the IBL units for the remote setting, getting inspiration from our previous workshops, EU projects (*Establish, SAILS, 3DIPhE*), or websites (*Exploratorium*). All units were implemented during the RISE online workshops with teachers in Professional Learning Communities of Teachers (PLCTs) in four project partner countries (Belgium, Ireland, Poland, and Slovenia). Some units were later incorporated into two international workshops, as indicated in the O2 and O3 books delivered together with this book.

Tables 2A & 2B collect all IBL units for a remote setting with the distinction of the student's age and the level of inquiry the unit is recommended for. Ages 7 – 12 indicate primary school level, ages 12 – 15 indicate lower secondary school level, and ages 15 – 19 indicate upper secondary school level.

Apart from three main levels of inquiry (see Fig. 2), namely, structured, guided, and open inquiry, other levels are linked to the units in the table. These are boundary levels (e.g., semi-open, the level between guided and open inquiry) and the levels indicating a specific format of the unit, e.g., guided inquiry (competition), suggesting the organization of the student competition at a guided level of inquiry.

Table 2A. Students' age and the level of inquiry recommended for the first 14 units.

Unit Title	Age	Level
Double Shadow	**13 – 19**	structured and guided inquiry
Spectroscope	**7 – 12** **13 – 19**	structured structured or guided
Chemical Reactions	**12 – 14**	structured with an extension to a semi-open inquiry
From playground swing to stopwatch: simple pendulum	**7 – 12**	guided inquiry
Why Do We Salt Roads in Winter?	**7 – 12** **13 – 19**	guided inquiry guided inquiry with an extension to an open inquiry
Friction	**13 – 19**	guided inquiry
How Much Can Carry an Aluminum Boat?	**13 – 19**	guided inquiry (competition)
How Firm is My Bridge?	**13 – 19**	guided inquiry (competition)
Building Towers	**13 – 19**	guided inquiry (competition)
Melting Ice Cubes	**13 – 19**	guided inquiry with an extension to an open inquiry
Earth rotation and rotation of water in a sink	**7 – 12** **13 – 19**	guided inquiry guided inquiry with an extension to an open inquiry
Measuring Speed	**12 – 14** **15 – 19**	guided inquiry with an extension to an open inquiry guided inquiry with an extension to an open inquiry
Indians, Bells & Whistling Bottles	**7 – 12** **12 – 15** **15 – 19**	structured inquiry guided inquiry guided inquiry with an extension to a semi-open inquiry
Cooking Spaghetti	**12 – 14**	open inquiry

The three last units (Table 2B) have a specific purpose, as they either focus on particular elements of the IBL cycle IBL or are suitable only for teacher training in developing the skills for teaching by inquiry.

Table 2B. Students' age and the specific purpose indicated for the last three units.

Unit Title	Age	Specific purpose
Ice Balloons	**12 - 19**	Brainstorming and raising inquiry questions
Concept Cartoons	**12 - 19**	Starting point for all levels of inquiry Based on possible misconceptions in science
Subtle shift	**Teachers**	Teacher training on how to transform the IBL unit to a higher level of inquiry

Double shadow

Teacher Guide

Mojca Čepič

Structured and guided inquiry

Introduction

Shadows are so frequently observed that one does not realize they depend on different circumstances, that they might have colours, that one object can cast several shadows if several light sources illuminate it, that shadow could have soft edges, etc.

This activity is twofold. It introduces the concept that shadow occurs when the light illuminating the object is absorbed, so the shadow always requires at least two actors, the light source, and a light absorbing object. In some cases, a careful observer may notice that despite a single light source more than one shadow of an object can occur. This, second phenomenon, is inquired by the activity.

The activity was already published in [1,2], therefore, in this contribution it will be only briefly presented. However, as no sophisticated equipment is required, we have adapted the activity to a remote setting, where hands-on means available in the household have to be used.

Curriculum topics

- Light
- Shadows
- Reflection
- Absorption

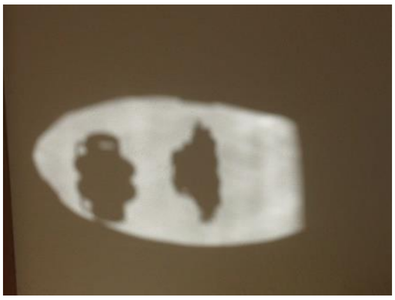
No ICT tools are needed for measurements and observations.

IBL level

The inquiry in the first part is structured, as students have to put up the setup using hands-on means available at home, that is, they have to provide circumstances in which the double shadow is observable. The second part of the inquiry is guided, as the goal to understand the phenomenon is given by teacher. The inquiry is focused on forming a tentative explanation and designing the testing experiment. Although the setup for testing experiments is rather simple, the articulation of the tentative explanation, ideas behind testing experiments, and the meaning of experimental outcomes for the tentative explanation, are not. Therefore, an important part of the activity is focused on communication skills.

Age of students

The light is considered several times during the education. However, shadows are considered so simple that they are usually mentioned at the elementary level only. But the elementary level is too early for this activity. The activity fits the introductory lectures on the light at the lower and upper secondary levels when ray diagrams are introduced. It is interesting and motivating. Besides, the phenomenon is easily explained by using ray diagrams, so this activity could be carried out with the purpose of training the presentation of phenomena related to light using ray diagrams.



Practicalities

Materials

For the SETUP

- Mirror. The mirror could also be replaced by a polished metal tray or a glass, even windows at night could act as a mirror.
- Torch. The usual torch on the mobile phone works well. Any other torch is good as well.
- Puppet. A small object that lacks any symmetry. The object should be much smaller than the mirror or its replacement. The puppet could be made of three to four LEGO bricks.
- Screen. A piece of white cardboard that is perpendicular to the mirror. One should be able to move the screen around to find the best position to observe double shadow. Alternatively, a wall is used as a screen to move the mirror around.
- Adhesive tape. Sometimes it is good to fix the puppet on the mirror or the screen in its place.
- One or two A4 papers, or a notebook or something similar to block the light.

ICT components

No ICT is needed for experimenting in person. However, a program that allows uploading photos and reporting conclusions, like *Google Jamboard,* is necessary for the comparison of results and discussion within and between groups if worked remotely.

Grouping

Groups of 3-4 students are preferable. Two students or individuals are usually caught in one way of thinking, for more students, it is usually difficult to maintain motivation for all participants in the group.

Setting

CLASSROOM.

Nest arrangement of students' tables is advised. The curtains are welcome. If darkening the room is not possible, students should use bigger papers, A3, for example, to block the daylight illumination of the setup when it is too bright.

REMOTE.

For the initial introduction of the task, students are in the main room. The teacher should check available materials and suggest alternatives if a student does not have proper equipment. Usually, replacements are found among kitchen tools, for example, aluminum foils for preserving the food may take a role of a mirror, although this is not optimal, as shadows are a bit blurred because the foil is never smooth enough.

For conducting experiments – students are put in breakout rooms randomly, notes are taken on the *Jamboard,* and each group takes a separate slide.

IBL Unit (30 – 40 min)

PART 1. Instructions for the setup (10 minutes)

The setup is discussed in more detail in references 1 and 2; however, let us briefly resume instructions.

Place the mirror to the table, place the screen perpendicularly to the mirror and fix it. Try to illuminate the screen with the light reflected from the mirror only, not directly. When the large bright light spot is seen on the screen, place the puppet to the middle of the mirror. If everything is set up correctly, in the middle of the light spot, two shadows mirrored with respect to the plane of the mirror should be seen.

Observe the shadow, its shape and try to find the explanation for the two shadows.

The teacher verifies if everybody is able to observe the phenomenon. Remote conditions require working cameras or photos from mobile phones should be uploaded to the Jamboard. The problem might occur when students use the same phone for photos and for illumination, but new generations usually find the solution easily, for example, taking a photo with a flash.

PART 2. Inquiry (25 min)

Students should play a little with the position of the puppet, of the light source and of the screen and try to find the situation when one or another shadow disappears.

They are encouraged to form a tentative explanation. Usually, students find the explanation already during the non-structured investigation of conditions, for which one or another shadow disappears. If they place the puppet near the edge of the mirror, which is away from the screen, there in no place for reflection of the light, which falls on the puppet and the upwards oriented shadow disappears. If the puppet is placed near the edge closer to the mirror, the opposite is true. There is no place for reflected light behind the puppet, and the downward oriented shadow disappears.

The testing experiment should test these to findings in alternative way, usually by covering the mirror before or after the puppet and by drawing the ray diagram that supports the testing experiment. Some students start to draw first, and experiment later, but they are rather rare.

PART 3. Communication of findings (5-10 min)

When students find the tentative explanation and support it with the testing experiment, they share their findings with peers. If this does not happen spontaneously, the teacher asks questions about conditions under which one shadow disappears. If this does not help, the teacher asks questions about the light that is reflected in front of the mirror, is it obscured by the puppet or not, and afterwards, he/she asks about the light that falls on the mirror behind the puppet, and how the puppet affects it. The encourages students to draw ray diagrams, although they are usually not really keen to do it.

Physics behind

Physics behind is discussed to subtle details in another unit (reference 1) and in the article (reference 2). As the former is publicly available, we advise the reader to inspect the reference for more details.

Conclusions

This activity is appropriate for lower and upper secondary school and can be used to encourage explanations using ray diagrams, to encourage design of testing experiments and to train students' communication skills.

References

1. Sokołowska, D. (2020) Inquiry-based learning to enhance teaching (e-book), M. Čepič and D. Sokołowska (Eds.), University of Ljubljana, Faculty of Education, p.41, available at https://archive3diphe.splet.arnes.si/files/2021/01/3D_VOLUME1.pdf
2. ČEPIČ, Mojca. Does a virtual image cast a shadow? *Physics education*. (2006) 41, p. 295-297.

Credits: p. 10 & 11 Double shadow, own work (M. Čepič)

Spectroscope

Teacher Guide

Dagmara Sokołowska

Structured & guided inquiry

Introduction

This unit aims to introduce the learners to the concept of the visible light spectrum, spectra of individual chemical elements (emission spectrum), light spectra of different sources, and their origin. The unit is designed at a structured IBL level.

Curriculum topics

It can be used in physics lessons about:

- Refraction and splitting of the light
- Diffraction grid
- Bohr's model of hydrogen

During classes, students use low-cost materials that are easy to find at home. If available, students may also observe spectral lamps (e.g., hydrogen, neon, helium, mercury, etc.).

IBL level

The module is embedded into the IBL cycle at two levels – the first at the structured inquiry level, and the second can be continued at the structured or guided inquiry level. The third part is recommended as a challenge between the groups of students.

Students build a model of a spectroscope and observe different sources of visible light, reflecting on spectra origin and the chemical elements composing the source.

Age of students

The module can already be used at any age of schooling, e.g., science classes for 7-12yo students and physics courses in lower or upper secondary schools (13-19yo). For younger students, a simpler version of brainstorming and an explanation of the observations should be used. Advanced brainstorming and conclusions are recommended for older students.

Practicalities

Materials

PART 1. Building a spectroscope

- One A4 sheet from the technical block (black or painted with a felt-tip pen on both sides in black)
- scissors
- a new or used CD (DVD is not recommended), preferably the simplest one
- a piece of adhesive tape (preferably opaque, e.g., insulating) about 3 m long
- a school ruler approx. 20 cm long

PART 2. Observation

- different sources of white light (smartphone, laptop, sunlight, wolfram bulb, energy-saving bulbs, etc.)
- (optional) candle, matches, a teaspoon of kitchen salt, an old kitchen knife
- (optional) spectral lamps with printed (or available online) spectra of elements constituting particular spectral lamps

Grouping

Groups of 2-3 students are preferable.

PART 1. Building a spectroscope
Students build spectroscopes individually, helping each other whenever it is needed to give a hand.

PART 2. Observation
Students observe different spectra in groups, discuss their observations, and come together to conclusions.

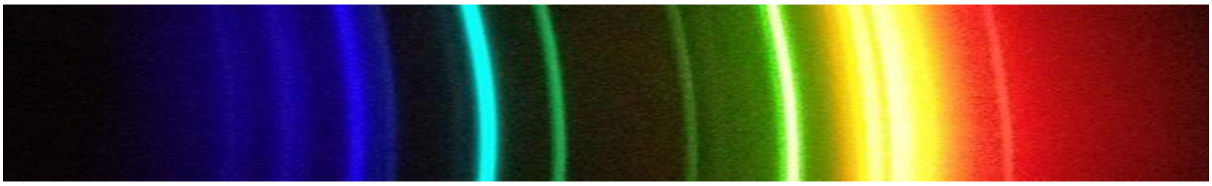
Setting

CLASSROOM.

Nest arrangement of students' tables is advised. Tables should be as far apart as possible. Students take notes in the worksheets.
Light sources should spread out across the classroom.

REMOTE.

For the brainstorming – students are in the main room. For conducting experiments – students in breakout rooms take notes on their observations and group conclusions on the *Jamboard* (each group takes a separate slide).



IBL unit

Brainstorming (10-15 min)

The brainstorming aims to introduce learners to the topic by benefitting from their everyday knowledge and previous knowledge from physics or music classes. All students should be given the floor.

A storyline can be composed around:

For ages 7-12.
On a sunny day, we go for a school trip, and suddenly, the light rain disturbs the trip for a while. What can we experience?

or any other story involving learners benefiting from their prior knowledge and experience, leading to the idea of the rainbow and splitting the white light.

The purpose is to learn that:

- Do light rays form straight lines?
- How come we see colored objects?
- How the rainbow is formed?
- What are the conditions for the rainbow to occur?
- Where else can we find the rainbow?
- Can we catch the rainbow in a box?

For ages 13-19 (depending on curriculum)
On a sunny day, we go for a school trip, and suddenly, the light rain disturbs the trip for a while. What can we experience?
or
The world is full of colors. What is the role of colors in human life? What are the scientific aspects of colors in terms of art, biology, chemistry, and physics?
or any other story involving learners benefiting from their prior knowledge and experience, leading to the idea of the rainbow and splitting the white light.

The purpose is to learn:

- Light rays form straight lines.
- How come we see colored objects?
- How is the rainbow formed?
- Does the rainbow exist as an object, or is it formed in our brain?
- Where else can we find the rainbow?
- How does the reflection on the mirror form?
- (optional) What is light dispersion, refraction, interference, and diffraction?
- (optional) What is a diffraction grid, and how can the CD become one?
- (optional) What is a chemical element spectrum, and how does it become “fingerprints” of elements?

PART 1. Building a spectroscope (30 min)

This part is organized as an activity at the structured level of the IBL since the purpose of part 1 is to build a tool for the observations of spectra from different light sources.

1. Students are divided into groups of 2-3.
2. Each student builds individually a model of a spectroscope following the instructions in Appendix 1.
3. Students either follow the instructions by reading and doing, or the teacher gives the instructions step by step, making sure that everybody gets to the end of the construction in more or less the same time.
4. Students are encouraged to help each other whenever necessary, bearing in mind that they all need to be well-equipped for the next part of the activity – observations.

PART 2. Observations (15-25 min)

This part of the IBL unit aims to observe spectra of light coming from various sources of white light.

Safety warning. Students should be informed of the danger of looking directly into the source of strong light (e.g. the Sun or strong lamp) and instruct how to avoid it.

1. Each student points the narrow slit of the spectroscope towards a window lit well by the sunlight and looks into the spectroscope through the window.

   Observation:

   - *Can you see two multi-colored stripes on the inside walls of the spectroscope? If not, try to look deeper. If much light is coming from the side of the window, cover the window with your hand (just like when you want to see something in the distance on a bright day), so that the eye and the window are in the shade.*
   - *Are the spectra you see on both sides of the spectroscope similar?*
   - *Is the spectrum continuous or discrete?*

Starting from this point, the unit can be continued at the level of structured inquiry (points 2-9). If the teacher wants students to be more independent, a guided inquiry level is recommended at which students meaningfully choose the sources of light by themselves.

2. Each student points the narrow slit of the spectroscope towards the lamp with the tungsten bulb.

   Observation:

   - *Does the spectrum look different than when you watched the sunlight?*

3. Each student points the narrow slit of the spectroscope towards other light sources: fluorescent lamps and lamps with energy-saving light bulbs.

   Observation:

   - *Does the spectrum look the same as when you watched the sunlight?*

4. The teacher lights on a candle.
5. Students point the narrow slits of their spectroscopes towards the flame and observe the spectrum of the flame.
6. The teacher takes an old metal knife, pours some salt on the knife surface, and places the knife in the middle of the flame. After a few minutes, the salt starts sparkling. At this moment, students point the narrow slits of their spectroscopes towards the flame.

   Observation:

   - *What remarkable difference can you see when you compare the spectrum of a candle flame with the spectrum of a candle flame with evaporating kitchen salt?*

7. Each student points the narrow slit of the spectroscope toward the white screen of the smartphone or toward a piece of white paper illuminated by a smartphone lighter.

   Observation:

   - *Does the spectrum look the same as when you watched the sunlight? What is the origin of differences?*

8. Each student points the narrow slit of the spectroscope towards some white fragment of the computer (laptop) screen.

   Observation:

   - *What other spectra does it resemble? What are the differences?*

9. Students in groups:

- collect their observations and formulate conclusions
- try to explain the observed spectra referring to their scientific knowledge.
- present their group findings to the class (last 10 min)

PART 3. A challenge: figure out the component of the spectral lamp (10-15 min)

This part of the IBL units can be organized as a challenge between the groups. Students working in groups observe the spectral lamps with their spectroscopes and try to match them with the spectra of particular elements (printed or available online). The spectral lamp indicators are hidden from students (lamps are numbered). Students write down their observations. At the end of the challenge, the teacher compares the results and announces the group which managed to make the best match.

Closing by a teacher (5-10 min)

The teacher summarizes the observations and explains (extends) all the aspects of physics behind the experiment that were not yet mentioned or clear to students.

Physics behind

The light that humans see as white is a mixture of different colors - from purple to red. White light can be split into a multi-colored strip called the light spectrum.

After splitting, the white light does not always form a uniform strip in which colors go smoothly from one to the other. The composition of the light depends on the source type.

If the source of light is high-density hot matter (e.g., the interior of the Sun or tungsten filament), then its spectrum seen through the spectroscope is continuous. If the source of light is a hot but diluted gas of a particular chemical element, then after splitting, we see single narrow lines characteristic of this particular element (so the spectrum becomes the element's "fingerprint"; compare to Bohr's model).

The spectroscope you built is based **on the transparent diffraction grid.** It is used to split the light reaching the slit into individual colors.

Sunlight and old-type light bulbs seen through the spectroscope split into a full, multi-colored spectrum. After splitting the light of a fluorescent lamp or energy-saving bulb, we see the full spectrum coming from substances covering the inner walls of these bulbs. But against the background of this uniform spectrum, we can also see very bright single lines. They come from hot and not dense mercury gas inside fluorescent lamps or energy-saving bulbs. When you put table salt into a candle flame, after a short while, the salt gets hot, and chlorine and sodium start to evaporate. Spectra of both gases are discrete; however, chlorine has plenty of low-intensity spectra lines, while sodium consists of a few lines, among which a double-line in yellow color is particularly intense. That is why when table salt is popping, one can see a distinct yellow line appearing on the full background spectrum of the flame just in the same rhythm as the rhythm of popping evaporation.

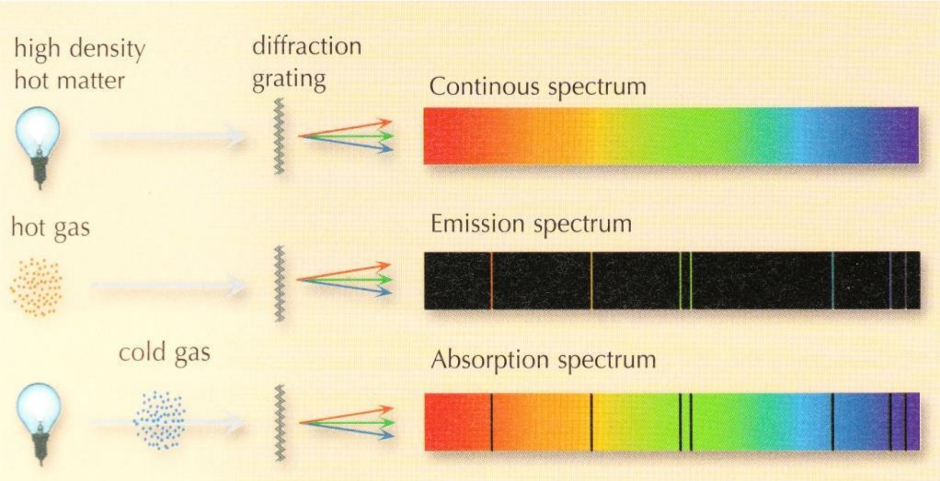


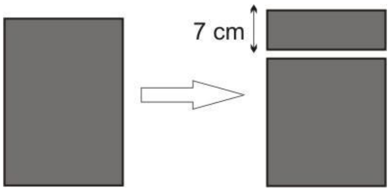
Fig. 1. Three types of spectra and their origin (https://www.scienceinschool.org/2007/issue4/spectrometer)

In turn, computer screens are designed to display any colors as a combination of three basic colors: red (red, R), green (green, G) and blue (blue, B). We call that RGB color system. Therefore, when observing the computer screen with a spectroscope you can see clear, thick lines: red, green and blue. In some screens, you can also see orange or purple (the remaining from the lamp brightening the screen).

Credits: p. 15 (Pixabay, free access);); p. 16 Rainbow, own work (D. Sokołowska); p. 17 Sodium lamp spectrum, (Mike Durkin, CC BY-SA 2.0; Flickr; p. 20 Students observing various sources of white light, own work (D.Sokołowska); p. 22 Three types of spectra and their origin https://www.scienceinschool.org/2007/issue4/spectrometer

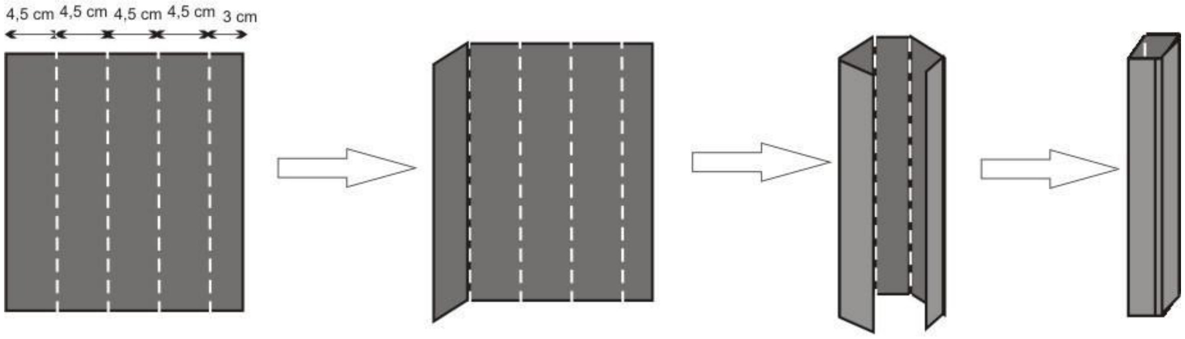
Appendix 1. How to build a spectroscope

A TASK: Design a spectroscope.

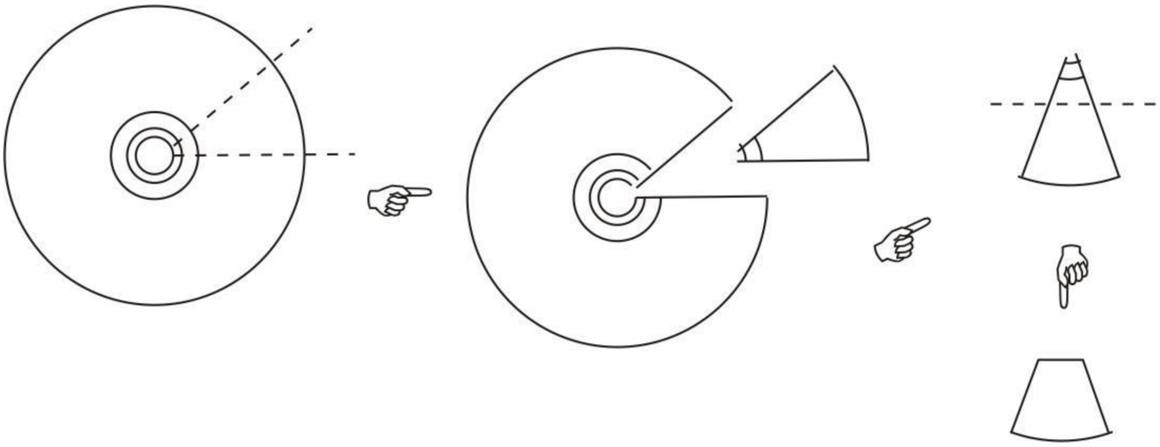


1. Cut a 7 cm wide strip from the top of the paper.

2. Make a cuboid sidewall from the rest of the sheet: starting from the left edge, measure 4.5 cm and fold the sheet inwards. Whenever you finish the forth fold a strip about 3 cm wide is left for the overlap. Glue the overlap with adhesive tape so that the side walls of the cuboid are put together.

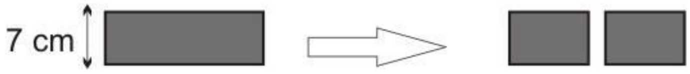


3. Cut the fragment from the CD with scissors as follows:



4. Adhere a strip of adhesive tape to the surface covered with this silverware, and then tear it off with the silverware. Stick and tear off the adhesive tape until you get rid of all the silverware.

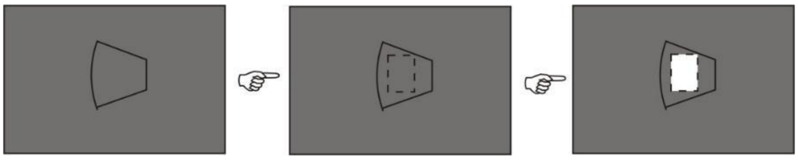
5. Cut the remaining strip of A4 paper (7 cm wide) in half, separating it into two rectangles. It will be the bottom of your cuboid, but don't stick it yet!



6. In the center of one rectangle, cut a slit ca. 2 mm wide and 3 cm long, parallel to the narrower side of this rectangle:

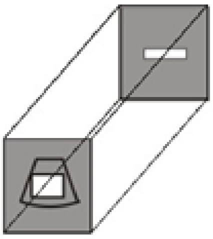
7. Make a the cuboid bottom from this rectangle and glue it to the walls of the previously made cuboid without bases.

8. Place the transparent fragment of the CD cut out earlier and outline its contour. Pu the CD aside and inside this contour cut a rectangular window that does not cross the contour.

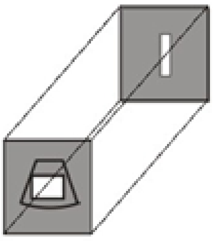


9. Adhere the fragment of the CD exactly in the place of the contour drawn earlier, covering the window. Glue the lid formed in this way to the previously made cuboid with its bottom already assembled. After gluing, a fragment of the CD should be placed on the inside wall of the bottom.

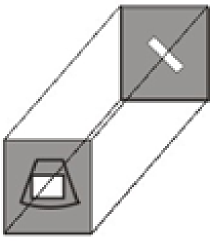
Please note: It is quite important that when looking through the window into the interior of the cuboid, the gap cut in one bottom and the window cut in the other bottom are properly rotated relative to each other:



CORRECT



INCORRECT



INCORRECT

10. Make sure that light enters the cuboid only through the slit and window. Cover all other clearances with adhesive tape.

That's how you build the spectroscope!

Credits: pp. 23 & 24 Construction of the spectroscope model, own work (D. Sokołowska)

Chemical Reactions

Teacher Guide

James Lovatt
Paul Grimes
Eilish McLoughlin

Structured & semi-open inquiry

Introduction

This structured inquiry unit aims to introduce learners to factors that affect the rates of reactions through experimentation with everyday materials.

Curriculum topics

It can be used in science lessons about:

- Reaction rates (acid and carbonate reactions)
- Factors affecting reaction rates (surface area, temperature, concentration)
- Gas identification
- Fair testing

Students use basic materials to complete this experiment. Most of the materials can be found in the home so students can easily do this in the school lab or remotely. Some of the extension activities proposed require additional materials such as limewater but these can be saved for the school laboratory.

IBL level

The unit is embedded into the IBL cycle at the level of structured inquiry. There are some proposed extension activities noted that allow the unit to be adapted for guided and open inquiry. Each of these adaptions will lead to the similar conceptual learning, however given the change in how the tasks are completed, students will gain opportunities to learn different inquiry skills.

Age of students

This unit is designed for lower secondary level (12-14 yo students). The unit described is very much an introduction to rates of reaction. The extension activities could be adapted and used with upper secondary level if the focus of the activities addressed more chemistry understanding and data analysis aspects.

Practicalities

Materials

PART 1 – PART 3.

- effervescent Vitamin C tablets
- beakers or drinking glasses (to take 150mL of liquid)
- mortar and pestle (to crush tablets)
- stopwatch
- pens, ruler (for completing worksheet and drawing graphs)
- worksheet and graph paper
- kettle for warm water
- ice
- thermometer
- weighing balance (home balance is fine)

Extension Activities.

For extension activities you will need additional material such as balloons, limewater, measuring cylinders, matches, splints, gas prep kit and pressure sensors (optional)

ICT component

There is no specific ICT element for this unit. If you wish to extend this unit you could use a pressure sensor to look at the pressure change caused gas production.

Grouping

Pair work is preferrable in this unit. Both students should engage in all task elements. If you are doing the more open inquiry extensions, you could group students in threes.

Setting

CLASSROOM.

Students should have sufficient space to be able to conduct their practical work in a safe manner. All superfluous equipment, such as school bags, etc. should be cleared away so students can move about safely.

REMOTE.

For the main discussions students should be in the main room. For conducting experiments – students can be in breakout rooms, however, if it’s a small group, it would be possible to keep all in the main room and pin different groups cameras to show what everyone is doing. Worksheets could be shared as digital documents which students complete live so you can monitor their progress and ask different questions. Students can be encouraged also to complete their graphs on paper or using software such as MS Excel, Google Sheets, Vernier Graphical Analysis. They can copy and paste their results into the main digital worksheet. It’s recommended the worksheets are shared with all at some point so they can compare their findings.

IBL unit

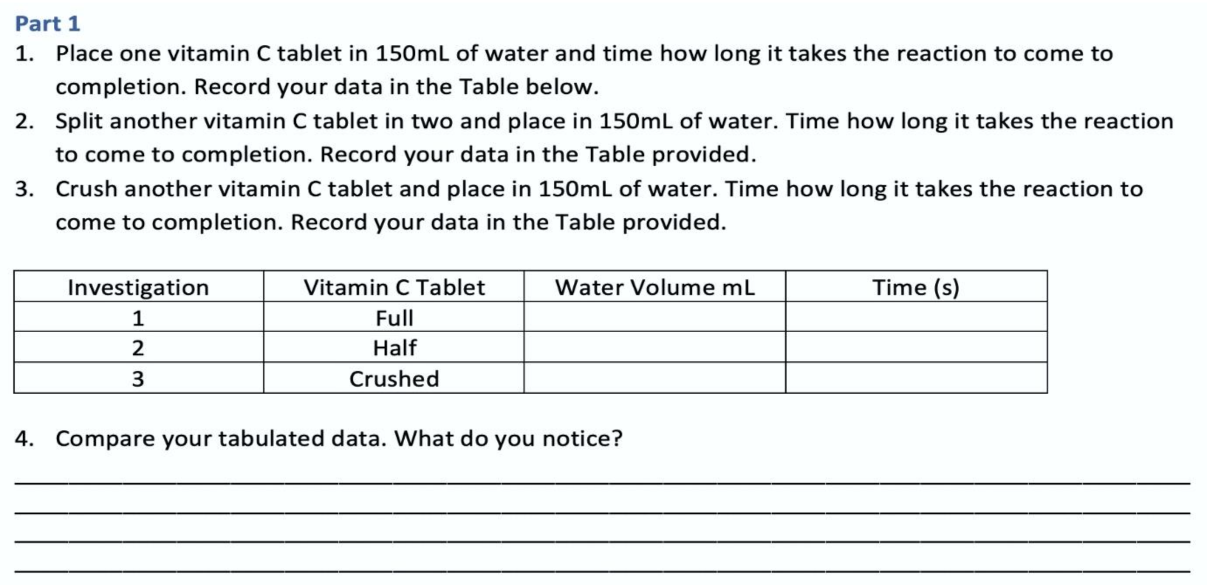
Introduction (10-15 min)

In the structured inquiry approach to this experiment, the focus is on students investigating factors that affect the rates of reaction. In this regard, they are not trying to figure out what the reaction is, the properties of Vitamin C tablets, or what gas is produced. These ideas are only explored through the extension activities noted. With this in mind, it's suggested to explain (in general terms) the acid-carbonate reaction and discuss how gaseous carbon dioxide is produced when the vitamin C tablet is placed in water. This should come at the end of a brainstorming session which is used to motivate students to engage in the activity. The teacher is free to decide how best to brainstorm with their students here as they will know their interests best. However, one suggestion would be to talk about food, diet, nutrients, health, and diseases such as scurvy and how it was common on pirate and explorers' ships. A storyline around this should be motivating to students and encourage further engagement in the lesson.

PART 1. Exploring surface area (20 min)

In this part of the IBL unit students will complete a structured inquiry worksheet. They will investigate the influence of surface area on the rate of reaction. They will tabulate data and interpret their results to draw conclusions.

1. Each student is given a workshop and an equipment box. They would normally have basic glassware already at their laboratory station. If not, these can be distributed as normal.
2. The students complete the tasks as per the worksheet instructions.
3. The teacher circulates to monitor student progress and pose questions: such as
    a. Why is it important to keep the volumes the same in the three investigations?
    b. How did you decide when the reaction was completed?
    c. What do you think the time will be in investigation two?
    d. Looking at your data for investigations one and two, what do you predict will happen in investigation three?
    e. What conclusions can you make based on your experimental data?



Part 1

1. Place one vitamin C tablet in 150mL of water and time how long it takes the reaction to come to completion. Record your data in the Table below.
2. Split another vitamin C tablet in two and place in 150mL of water. Time how long it takes the reaction to come to completion. Record your data in the Table provided.
3. Crush another vitamin C tablet and place in 150mL of water. Time how long it takes the reaction to come to completion. Record your data in the Table provided.

Investigation	Vitamin C Tablet	Water Volume mL	Time (s)
1	Full		
2	Half		
3	Crushed		

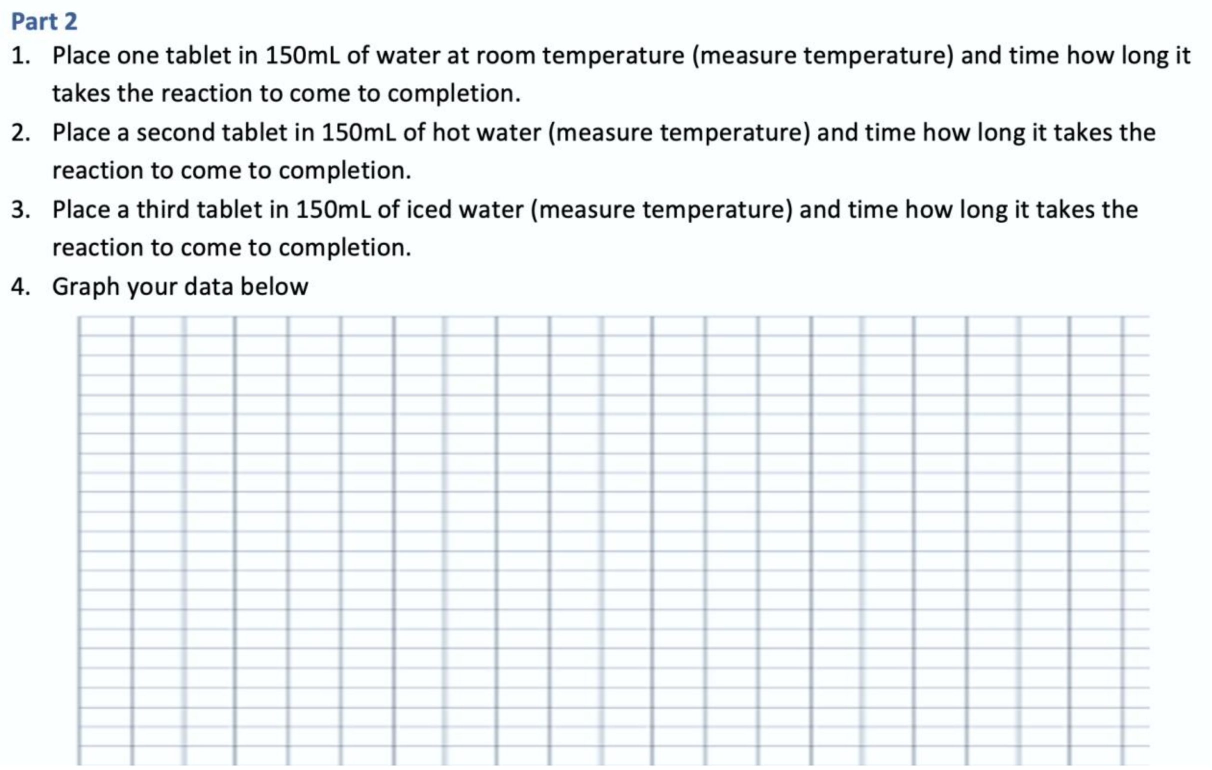
4. Compare your tabulated data. What do you notice?

____
____
____
____

PART 2. Investigating the influence of temperature (20 min)

This part of the IBL unit aims to investigate the influence of temperature on the rate of reaction. Students use the same equipment as before. In this situation, students should learn from part 1 and create a data table for themselves so they can use the data to graph their results. Students learn to graph data and graph analysis.

1. Students move on to part 2 of the worksheet
2. They are asked to carry out three investigations to determine the time it takes the reaction to go to completion with hot water, room temperature water, and ice water.
3. Students tabulate and graph their data
4. Finally, they are asked to draw conclusions from their graphs.
5. The Teacher circulates and poses questions such as:
    a. How will you keep track of your data?
    b. How did you ensure that you're completing fair investigations?
    c. How do you know that each Vitamin C tablet is similar?
    d. Is it okay if different groups use a different criterion for the end point?
    e. What data goes on the x and y-axis?
    f. What can you conclude from your graph?



Part 2

1. Place one tablet in 150mL of water at room temperature (measure temperature) and time how long it takes the reaction to come to completion.
2. Place a second tablet in 150mL of hot water (measure temperature) and time how long it takes the reaction to come to completion.
3. Place a third tablet in 150mL of iced water (measure temperature) and time how long it takes the reaction to come to completion.
4. Graph your data below

PART 3. Drawing conclusions and Extensions (10 min)

This is the last part of the unit where students are asked to reflect on their learning and make conclusions based on their two investigations.

1. This can be a group activity. It's recommended to bring two pairs together to discuss their data and how they conducted the experiments. Note: Even though the experiments are quite prescribed, students can often make different decisions about end points and how they interpret data.
2. The purpose of the drawing conclusion part is for students to reflect on the factors that influence rates of reaction and the fair testing aspect of the investigations. This is particularly relevant to end points, size of tablets, keeping the amount of water the same etc.
3. Students should use their worksheet to write up their final conclusions.
4. There is an opportunity for the teacher to probe about further investigations that could be carried out. For example, the teacher could ask students to design an experiment for homework that could be used to confirm which gas has been produced. This extension would build on their learning about fair testing learning and would encourage students to think about how to design an investigation. The designs could be peer interrogated in the next lesson and students refine and test their approach.

Part 3

Using the data gathered in Part 1 and Part 2 what can you conclude about the reaction of a vitamin C tablet and water.

____
____
____
____
____

PART 4. Alternative Activities – (45 min)

In this unit the focus was on factors affecting rate and fair testing which were explored using a structured inquiry approach. In Extension Activity 1 we will look at how the same conceptual understanding can be developed through an alternative semi-open inquiry approach. In Extension Activity 2, we will look at how the same concepts and additional concepts can be explored through an open inquiry approach.

Alternative Activity 1.

This activity is directly taken from the SAILS EU Project on reaction rates – Activity B, developed by Dr Odilla Finlayson. It can be found online: http://www.sails-project.eu/units/reaction-rates.html

In this approach students are given a challenge task:

"I'm usually in a rush in the morning and I want my vitamin drink to be ready as quickly as possible. Carry out investigations using one vitamin C table per experiment with 100 mL of water to make the reaction go to completion as fast as possible.
Keep notes on the factors that make the reaction go more quickly."

The focus on this approach is the factors which affect the rate of reaction and experimental design. The approach is semi-open as students are given a set task which has a known outcome. They are also limited by the equipment available which guides their experimental design. Many of the teacher questions used in Part 1-3 can also be used for this task. From experience, students tend to record their data on scraps of paper and don't think of drawing tables or graphs. It's suggested that teacher prompts can be used to require. They can also struggle due to changing too many variables at once. These common errors are great learning opportunities for the students and can be probed by the teacher.

Alternative Activity 2.

This alternative adopts an open inquiry approach. Students are given a very broad question:

"Using the materials on the table, find out whatever you can about the structure and behaviour of vitamin C tablets . Work with a partner and select whatever materials you like. You may also request additional materials."

Through this approach students have more control over the investigations that the complete. Some will focus on the properties of vitamin C and investigate the gas produced. Others will end up completing similar investigations regarding the factors influencing the rate of reaction. From experience teacher facilitation is extremely important here and it's also essential to know what you would like to achieve from the approach. If you want to focus on experimental design, you can prompt students to think about fair testing etc. If you want to focus on data collection you can challenge students about how they will record and analyse their data. If you want to focus on rates of reactions you can prompt in that direction, if you want them to explore how to trap and analyse the gas from the reaction you can stir them that direction. There are many different routes this approach can take, and students learn many skills about carrying out investigations, however it's also important that they don't get overwhelmed, hence the teacher should be clear on which direction they would like to push students once they've had time to explore on their own.

Additional Recommendations

The SAILS-EU unit of reaction rates discusses a few other approaches to teaching this topic using the same experiment of dissolving vitamin C in water. Some of these delve deeper into the chemistry understanding. It's recommended to review these as extensions to this unit.

Closing by a teacher (5 min)

This is an opportunity for the teacher to check student understanding of related science concepts and fair testing. To close the lesson the teacher summarizes and where relevant extends the lesson to the next topic/class.

Science behind

The concept in this unit is quite basic in that it looks at the factors which affect the rate of reaction, namely surface area, temperature and in the extension activities concentration. This is explored in the context of effervescent vitamin C tablets. The reaction that is of importance is an acid-carbonate reaction producing carbon dioxide, salt, and water. Sometimes there is confusion regarding the role of water where students can think it is the acid in the acid-carbonate reaction when in fact, the acid and carbonate are already in the tablet, but the water allows them to react together. If students look at the ingredients on the packet, they will see that it will contain vitamin C and sodium carbonates. There will be other acids and ingredients, but for the purpose of this unit, they can be ignored.

Credits: pp. 25 & 26 Microsoft Office Stock Images; p.32 Workshop Images from RISE Project, Dublin

Co-funded by the
Erasmus+ Programme
of the European Union

From playground swing to stopwatch: simple pendulum

Teacher Guide

Ana Gostinčar Blagotinšek

Mojca Čepič

Guided inquiry

Introduction

Unit introduces learners to the properties of the simple pendulum which influence its oscillating period through guided inquiry.

Curriculum topics

It can be used in physics or science lessons about:

- simple harmonic motion
- simple pendulum and its period/frequency
- measuring distance, time, mass
- (guided) IBL
- principles of measurement and data management

Students use low-cost materials, easy to find at home. They also need a stopwatch (or mobile phone).

IBL level

The module is embedded into the IBL cycle at the level of guided inquiry.

Age of students

The module can already be used in science classes for 7-12 yo students as an exercise in measurement skills (length, time, mass) and data management. In lower secondary school and high school, it is useful to implement IBL, particularly fair test and simple harmonic motion (oscillations).

Practicalities

Materials

- approximately 1 m of thin string, sewing thread or yarn
- weights (candies, lumps of sugar, beans …)
- stopwatch (preferably on the smartphone)
- supporting object to hang the pendulum from

Grouping

Groups of 3-4 students are preferable.

Teacher (or students among themselves) assigns the roles: secretary (taking notes and organizing data), technician (taking care of equipment), and 1-2 investigators (performing the experiments and making measurements).

Setting

CLASSROOM

Nest arrangement of students’ tables is advised.

REMOTE

For the brainstorming – students are all together in the main room. For conducting experiments – students are in breakout rooms, taking notes on the *Jamboard* (or similar; each group takes a separate slide).

IBL unit

Brainstorming (10-15 min)

The brainstorming aims to introduce learners to the topic by benefitting from their everyday knowledge and previous knowledge from physics or science classes. All students should be given the floor.

A storyline can be composed around:

What kind of clocks our grandparents used? How were first mechanical clocks made? What properties determined their period/time needed for a swing? What is your experience about that from the playground swings?

Legend has it that Galileo invented the clock with a pendulum after observing chandeliers swing in the draft.

Each group (or student) assembles its own pendulum and measures the time it needs for a swing. It is not expected that they already know how to properly measure the period, so time needed for a swing between the extreme positions is acceptable. Precise instructions about the length, mass and amplitude are intentionally omitted, so the resulting measurements are different. As they most probably make very different pendula, different results are expected. Students are then asked to hypothesize what is the reason for differences and if necessary, reminded, that also their pendula and the way they oscillate are different.

How do pendula differ?

The purpose is to notice that pendula differ in:

- length
- mass
- amplitude (largest distance from resting position while oscillating)

Vocabulary

Before proceeding with the activity, the teacher should check if students have the necessary language skills: oscillation, period, amplitude, and displacement should be defined and explained if the lesson is about the simple (sinusoidal) oscillations, or avoided and replaced by descriptions, used in everyday language if the lesson is about measurement skills or IBL process only.

PART 2. What does the period of a simple pendulum depend on and how? (25 min)

This part of the IBL unit aims to investigate the relationship between the period of oscillation and the properties of a pendulum (mass and length) and initial displacement (amplitude).

1. Each group or student measures the period of their pendulum.
2. Teacher asks students to report their results, which are usually small (less than 1 s) and leads the discussion how to improve the accuracy of measurement (repeating measurements, measuring time for 10 oscillations instead of single one). Thus, she or he also checks if the students understand what and how to measure to determine the period of the pendulum.
3. Students are asked to hypothesis which property (chosen from the differences among the pendula listed above) of the pendulum determines the period of oscillation and how are they related.

Students in groups:

- Form their Inquiry questions, transforming the hypothesis into a “How does … (my chosen property) influence the period of the pendulum?” question:
    - *How does the period of the pendulum depend on the length/mass/amplitude of the pendulum?*
- Discuss and put forward a hypothesis.
- Students plan how to test their hypothesis through simple inquiry, systematically changing only one (chosen) property of the pendulum and measuring its period. Teacher should challenge them how to organise data recording or instruct them to do it in tables. Discussion about the appropriate execution of measurements and number of repetitions is also advisable.
- Conduct the experiments;
- Collect and record data;
- Draw conclusions;
- Present their group findings to the class.

4. The only significant property affecting the period (length of the pendulum) can easily be determined from the results.

PART 3. Making a stopwatch (5 min)

This is a concluding activity and a possibility for a teacher to assess students' understanding of the topics.

1. Groups (or individuals) are challenged to make a stopwatch (a pendulum with a period as close to 1 s as possible).
2. Students change the length of their pendula and measure periods.
3. Students find the pendula with length approximately 25 cm have the period of 1 s.

Closing by a teacher (5 min)

The teacher summarizes and extends the lesson to the next topic/class.

Physics behind

Simple pendulum consists of a point mass m, suspended from a pivot on a massless string of length L; in practice, this means a small object (weight) hanged on a thin thread which is free to oscillate without obstruction (except from the surrounding air). When displaced from initial resting position and then released it will oscillate around it with a constant amplitude. If the initial displacement is small (angle between the thread in resting position and at maximum displacement smaller than 15^o) it behaves like simple harmonic oscillator, meaning that its period T is independent of the initial displacement (amplitude) or mass and depending only on the length of the pendulum L and acceleration due to gravity g (Halliday et all, 2014):

$$T = 2\pi\sqrt{\frac{L}{g}}\,.$$

Amplitude decreases in everyday situations because of the air resistance, but this does not affect the period, which is almost independent of the amplitude, if amplitudes are small. If the angle of the string with the vertical does not exceed 10°, the effect of the amplitude cannot be measured within accuracy of simple means used in the activity. However, even for larger amplitudes, the effect of amplitude on the period is very weak. This property makes pendula so useful for measuring time; pendulum clocks were the most accurate time-measuring devices from 1657 when Huygens invented the first one, till 1930, when quartz clock became a time standard (Wikipedia).

References:

Halliday, D., Resnick, R., Walker, J. (2014). *Fundamentals of Physics*. Wiley.

https://en.wikipedia.org/wiki/Christiaan_Huygens (Christiaan Huygens - Wikipedia)

https://en.wikipedia.org/wiki/Pendulum (Pendulum - Wikipedia)

Credits: pp. 34 clock with a pendulum, own work (M. Čepič); p. 35 playground swings, own work (A. Gostinčar Blagotinšek); p. 38 workshop participants at work, own work (A. Gostinčar Blagotinšek).

Co-funded by the
Erasmus+ Programme
of the European Union

Why Do We Salt Roads in Winter?

Teacher Guide

Mojca Čepič

Guided inquiry

Introduction

This unit aims to introduce the learners the concepts of freezing and melting, the melting temperature and how to influence this temperature. The inquiry leads to understanding why icy roads are salted in winter. The inquiry aims to reduce the persistent conception that streets become warmer, if they are salted and therefore the ice melts, and not the other way around. The ice melts as the salted water freezes at lower temperature than a regular one.

The topic is interdisciplinary and connects chemistry and physics.

Curriculum topics

It can be used in physics lessons about:

- Phase transitions in general
- Freezing and melting
- Transition temperatures
- Condensation and evaporation
- Water in the air
- Hydrogen bonding
- Effects of ions on hydrogen bonding

During classes, students use low-cost materials, easy to find at home. If students have thermometers, the measurements of the temperature can be included, otherwise the temperature is semiquantitatively deduced from observations.

IBL level

The module is embedded into the IBL cycle at the level of guided inquiry. An extension to the open inquiry level is possible. Students experience different sorts of condensation, which are easily inquired, but are not usually observed in everyday life.

Age of students

The activity is appropriate for elementary school level, at the observation level. In the lower and upper secondary school, the experiments are included in learning about phase transitions and heat transfer. The unit can be developed to an open inquiry or extended to chemistry and physics for similar phenomena easily demonstrated and inquired with heating pads.

Practicalities

Materials

PART 1.

- Glass
- Ice cubes
- Paper towels
- Water (optional)

PART 2.

- Salt
- Spoon
- (optional) Thermometer

ICT component

No ICT besides regular remote communication channels is needed.

Grouping

Groups of 3-4 students are preferable.
Students assign among themselves the roles: secretary (taking notes, photos), reporter (taking care about gathering data in an organized way, leading the organization of presentation to other groups) and 1-2 investigators (taking measurements).

Setting

CLASSROOM.

Nest arrangement of students’ tables is advised. Tables should be as far apart as possible to enable access to the teacher. Students take notes in the worksheets. Worksheet is attached in the appendix.

REMOTE.

For the brainstorming – students are in the main room. For conducting experiments – students are in breakout rooms, taking notes on the *Jamboard* (each group takes a separate slide). Presentations are prepared using *Jamboard* or programs for preparation of *Presentations,* which allow the whole group working on the presentation at the same time.

IBL unit

Brainstorming (10-15 min)

The brainstorming aims to introduce learners to the topic by benefitting from their everyday knowledge and previous knowledge from everyday life.
Except students that live in warm areas, most of them have experience with icy roads and pavements and salting them to prevent people and cars from sliding. Besides, students have experience with cold drinks in summer.˚
All students should contribute. If not, the teacher should encourage them by simple questions about their experience.

A storyline can be composed around two everyday experiences:

a) *What happens with the glass of water with ice cubes in summer?*
b) *How is sliding on icy roads and streets prevented during winter?*

Ad a) Cold drinks in summer are popular. Everybody has drunk one or many. In fact, a cold drink with icy water is very reach with physics phenomena, about which an awareness could easily be raised. Here, a few questions are given, which help to build a story around memories on summer.

- *Why are ice cubes added to drinks in hot days?*
  To cool the drink. To decrease the temperature of the drink.

- *What happens with the drink?*
  It cools down. Ice cubes melt.

- *What usually happens with the glass from outside?*
  It becomes wet. After some time, when the glass is empty or the drink gets warm, it dries again. Not all students remember that.

Ad b)

- *Did you ever see crystals of ice on outside of the glass with the cold drink?*
  The answer is no, but not many students remember that. Activity provides an answer later.

- *Did you ever see crystals of ice on surfaces during the summer? What were the conditions?*
  If you take something from the freezer, it gets ice crystals on it. Not many students are aware of that.

Ad a,b)

Some questions regarding physics and chemistry phenomena could be raised as well.

- *At which temperatures water freezes in winter?* Below 0°C
- *At which temperatures snow melts in winter?* Above 0°C
- *What is the temperature of ice, when it is melting of the water, when it is freezing?* 0°C.

The last three questions remind students that freezing and melting occurs always at the same temperature that is called the melting temperature or the transition temperature from the liquid to the solid state.

PART 1. Melting of regular ice (structured inquiry, 10 minutes)

At the end of the brainstorming, **a short experiment/observation** is carried out by students.

1. Each group of students fills a glass with ice cubes, wait ,and observe.
2. Students are asked to use all their senses, to observe, what happens. They should observe, listen, touch the glass of water, the water in the glass, taste the water etc.
3. Students should be stimulated to find out that the glass and the water in the glass are quite cold to the touch. Ice cubes gradually melt and disappear, and the water becomes gradually warmer again. The glass is also cold from outside and it becomes wet from outside. But not everywhere, only at the places, where the ice or water from the melted ice is. It is called the *condensation of water* on the surface of the glass. It occurs at higher temperatures of water in the glass if the air is humid and at lower if the air is dry, but in general, at room temperature the condensation of water at glass surfaces of the water with ice cubes is always observed.
4. From where the water comes to the glass? If there are any other ideas than from the air, the testing of these ideas should be discussed. For example, if anybody suggests that water comes from the water inside the glass, the glass could be covered by a piece of glass to prevent the water climbing across the edges, or an empty but cold glass is taken from the refrigerator and it becomes wet even if there is no water in it, or another glass is filled by cold oil from refrigerator but still, the water appears on outer surfaces[1]. If students become interested in discussion from where the water comes to the outer surfaces of the glass, 10 more minutes are needed.
5. Students are asked to investigate conditions under which the condensation of water occurs. This part is already an open inquiry, which leads to conclusion that there is a certain temperature interval above the melting temperature where the condensation occurs.
6. Teacher stresses the conclusion that even without the thermometer, one can say if the water in a glass is cold, because of condensation. Besides, if the ice cubes of regular water are melting in the glass, the water condenses but never freezes.

PART 2. Salted ice cubes (25 min)

This part of the IBL unit aims to investigate effect on salting the ice cubes.

1. Each student is given a glass filled with ice cubes.
2. Teacher asks students to add one full normal spoon of salt on the ice cubes and mix the content of the glass with a spatula. Students are asked to use their senses to observe, what happens. They should observe, listen, touch the glass of water, the water in the glass etc.
3. The ice cubes start prickling. They melt faster than in the case without a salt. At the outside of the glass, ice crystals are formed. The water in the glass is very cold, but if it is really colder than in glass with ice cubes without has to be verified with a thermometer. Without the thermometer, the brainstorming and comparison of the two experiments is needed.
4. Teacher asks students *to compare properties of both glasses.* If needed, new ice cubes are put in the first glass.
5. Students in groups:
    - Are asked to compare the appearance of both glasses.
    - Are asked to compare the temperature of both glasses by touch.

- Are asked to form a prediction, the content of which glass is colder.
- To form an explanation for their prediction.
- To measure the temperature in of the mixture in each glass if thermometers are available.
- Optional: If thermometers are available, students can plan a systematic study on effects of salt on the melting temperature
- Based on observations of outer surfaces of both glasses, students draw conclusions on the temperature of the regular melting ice and on the temperature of the salted ice.
- They draw conclusions on the effects of salting the ice on the melting temperature.
- Students present their group finding and try to answer the question in the title. (last 5 min)

6. The teacher stresses the conclusions of the second part. On the glass with salted ice cubes crystals of ice are formed. This indicates, the salted ice cubes have lower temperature than regular ice cubes. As the melting occurs at a certain well defined melting temperature, ice crystals at outer surfaces of a indicate clearly, salting the ice lowers the melting temperature. If thermometer is available, one can easily measure for how many degrees.

Left: Ice cubes with salt. Thermometer indicates more than 10°C below zero. Right: Regular ice cubes. Thermometer indicates the regular melting temperature of water 0°C.

Closing by a teacher (5 min)

The teacher summarizes and extends the lesson to the next topic/class.

Surprisingly, in spite of personal experience that in salted ice crystals of ice condense on the outer surface of the glass, which never occurs with a regular water, students still repeat a general concept that ice should become warmer to melt, and the salt warms up ice in winter.

Teacher should discuss this into detail, potentially comparing the process of melting the regular ice at the temperature of air above $0°C$ and freezing below $0°C$. The properties of water such as a melting temperature change if the salt is added, which is rather difficult to comprehend by several students. Therefore, the teacher may discuss a fictitious material with a different melting temperature, for example, with a melting temperature$-10°C$. At which temperatures does this material melt, at which freeze? After the concept of the melting temperature is clear, the salted ice is considered as a fictitious material and its reaction on usual temperatures in winter, when icy surfaces are slated, are discussed.

Physics behind

The addition of salt into water changes the freezing/melting temperature. The phenomenon is called "cryoscopy". The ions of dissolved salt "destroy" hydrogen bonds, which increases the melting temperature of water, which according to the components would be at least 100 K lower.

The decrease of melting temperature depends on the concentration of salt and reaches about -17°C. In times when freezers were not available, salting the ice was the only way to cool down materials below $0°C$ in the absence of cold air in winter. At the beginning of the previous century, salted ice was used in preparation of ice. The ice was carried from ice caves where the snow was intentionally collected in winter and kept to summer.

To prepare an ice cream, ice was put in a bowl, severely salted and stirred. This mixture presented a cold bath. Next, another bowl from a good heat conductor like copper was put in this mixture bowl. Then, the components of the ice such as vanilla flavoring and cream were added to the bowl and a maid stirred it for several hours. One can imagine that an ice-cream was a very expensive delicacy at that time.

References

ETKINA, Eugenia, PLANINŠIČ, Gorazd, VAN HEUVELEN, Alan 82018). *College physics : explore and apply*. 2nd ed. New York: Pearson, p. 981

Credits: pp. 40, 41 & 45, own work (M. Čepič)

Co-funded by the
Erasmus+ Programme
of the European Union

Friction

Teacher Guide

Dagmara Sokołowska

Guided inquiry

Introduction

This unit aims to introduce the learners to the concept of static and kinetic friction. Special emphasis is put on the formulation of inquiry questions and fair testing. Since friction is experienced in our lives every day, it is very important that students realize different types of friction, advantages, and disadvantages of friction presence in particular situations, as well as understand factors influencing friction.

Curriculum topics

It can be used in physics lessons about:

- static friction
- kinetic friction

During classes, students use low-cost materials that are easy to find at home. Measurements are taken using the dynamometer.

IBL level

The module is embedded into the IBL cycle at the level of guided inquiry. Students experience different aspects of static, kinetic, and even torque friction force and its dependence on various variables.

Age of students

The Brainstorming proposed below should start any IBL unit. PART 1 (Two books) of the module can already be used in science classes for 7-12yo students. PART 2 is recommended for courses in lower secondary school.

Practicalities

Materials

PART 1.

- Two thick books of the same size

PART 2.

- cuboid blocks made out of wood, plastic, or metal (with smooth sides)
- strong adhesive tape
- dynamometer 0-1 N and 0-5 N; if not available – an accelerometer in a smartphone app can be used together with a scale (e.g., kitchen scale)
- cards of sandpaper (at least 0,5 m long)
- table or floor with a smooth surface
- (optional) A4 paper sheet
- (optional) ten regular cylindrical objects of the same size (pencils, board pens)

ICT component (if dynamometer is not available)

PART 2.

If a dynamometer is not available, it is possible to use any app with a force meter or accelerometer. In such cases also the scale is needed to measure the mass of the object.

Grouping

Groups of 3-4 students are preferable.
Students assign among themselves the roles: secretary (taking notes), mechanics (performing the experiment), and 1-2 investigators (taking measurements).

Setting

CLASSROOM.

Nest arrangement of students' tables is advised. Tables should be as far apart as possible. Students take notes in the worksheets.

REMOTE.

For the brainstorming – students are in the main room. For conducting experiments – students in breakout rooms, taking notes on the *Jamboard* or *Miro* (each group takes a separate slide).

IBL unit

Brainstorming (10 - 15 min)

The brainstorming aims to introduce learners to the topic by benefitting from their everyday knowledge and previous knowledge from physics or music classes. All students should be given the floor.

1. **A storyline** can be composed around one of the stories:
   - *I fell today on my way to school. Do you know what could have happened?* (in winter time)
   - *I fell today running to the classroom.*
   - *I want to make a raw salad with carrots or beetroot… (it should direct to the use of a grater)*

or any other story involving learners benefiting from their prior knowledge and experience.

2. **Discussion based on observation** on the title picture of this module (or a cartoon visualizing a funny situation with low friction) can be used as another format of brainstorming.

The purpose is to learn that:

- Friction is common in everyday life.
- How do we benefit from friction?
- How does friction bother our lives?
- What to do to decrease friction?
- What to do to increase friction?
- (optional) How would life look like without friction?

PART 1. Two books (10 min)

At the end of the brainstorming, **a short experiment** is proposed with the use of two thick books. If the module is continued to PART 2, PART 1 can be included in the brainstorming as its extension.

1. *Two books* experiment is described in Appendix 1.
2. Students reason about the results of the experiment, and the first step of understanding of the properties of friction emerges from this experiment.

PART 2. Moving off and sliding (45 - 60 min)

This part of the IBL unit aims to investigate the influence of different parameters on static and/or kinetic friction force. Extension to torque force is possible.

1. Students are given two wooden blocks and a few dynamometers. A research question is raised:
   What can influence the friction between a wooden block and a table (school desk), and how?
2. There are two possibilities for the subsequent work:
   • Students discuss on a forum the choice of possible factors influencing one, two, or three types of friction, and the teacher and students select the factors to investigate (basic scenario).
   • Students start to work in individual groups on this question (advanced scenario)
3. In what follows, we describe the advanced scenario.
4. Students start to work in groups of three or four. At first, they consider different factors (physical quantities) that may affect the value of friction force. This way, the identification of variables is completed.
5. Students link phenomena and quantities to the measurement with the available equipment.
6. Students select types of friction (the teacher can decide to select only one type of friction) and factors influencing (in their opinion) friction, thus choosing and identifying dependent and independent parameters. They also need to realize what controlled variables are, which they will keep unchanged, and how they will control these variables. This way, the fair tests are secured.
7. While working in groups, students formulate a specified inquiry question (or a few questions).
8. Students develop their group hypotheses.

The first lesson ends here or after completing the next step.

9. Students plan in detail their investigation in groups, focusing on four key questions:
   - *What we plan to do and how?*
   - *How will the tasks be distributed among us?*
   - *What do we need (list of equipment and tools)? – choice of the right components*
   - *Which data will we collect? How will we record them?*
10. The teacher monitors the work of the groups all the time, but especially at this moment the teacher approaches students with probing and clarifying questions about their investigation.
11. Students conduct an investigation and collect data.
12. Initial data analysis takes place. If the results do not lead to the conclusions and answers to the inquiry question, or results are inconsistent, students may alternate their investigation plan and do more experiments.
13. Students in groups review the collected evidence, interpret their meaning, and draw conclusions. Students articulate their findings. The teacher avoids comments on the correctness (or inadequacy) of the hypotheses and their explanations; however, s/he discusses the conclusions drawn from acquired data.

14. Groups of students report their findings to each other in a coherent and concise way, and compare them with the results of other groups. Proportional reasoning may be recalled here.
15. After completing the investigation, the teacher may ask students about their suggestions on the extension of this inquiry or inquiry on related topics for further study.
16. Students come back to the experiment TWO BOOKS. They discuss in groups and write down possible explanations for the phenomenon observed in this first experiment, using scientific expressions and scientific reasoning. They may discuss their explanations with other groups or groups.
17. In groups of four, students consider and discuss:

- The ways of decreasing friction in situations in which friction impedes human life, work, etc.
- The ways of increasing friction in situations in which friction supports human life, work, etc.

18. The teacher may summarize their ideas in one list.
19. At the end of the activity, students take individual notes summarizing what they learned or have heard from their colleagues but not noted yet.
20. Optional, but recommended: As a final step, students are asked to draw, individually or in pairs, a mind map around FRICTION on the basis of their knowledge recalled and acquired, as well as experiences gathered during the activity. This may be given as homework and/or treated as a revision of learning.

Closing by a teacher (5 min)

The teacher summarizes and extends the lesson to the next topic/class. For example if the teacher decided in PART 2/point 6 to select one type of friction, during the next lesson students can focus on another type of friction.

Physics behind

Friction between two solid objects is called dry friction and is related to the motion or possible motion of two solids in contact. It arises from the interaction of the roughness of both surfaces (through electromagnetic forces). Dry friction can be subdivided into *static friction* (between non-moving surfaces that would move if the friction is lower or absent), *kinetic friction* between two flat surfaces that move against each other, and *rolling friction* which appears when an object rolls on a surface.

Dry friction is mainly described by three laws: Amonton's First Law (*The force of friction is directly proportional to the applied mass*), Amonton's Second Law (*The force of friction is independent of the area of contact between two flat surfaces),* and Coulomb's Law of friction (*Kinetic friction is independent of the sliding velocity*).

Dry friction depends on the surface materials of two contacting bodies. Friction is governed by the model stating that kinetic friction and maximal static friction are proportional to friction coefficients (kinetic and static, respectively) and the normal force value. In general, for the same two materials, the friction coefficients are different for different types of friction: the highest is the static friction coefficient and the lowest is the rolling friction coefficient.

On the ice, the movement (e.g. of a skate) starts with dry friction. However, the work of dry friction force is dissipated as heat; thus, the ice just under the object usually melts. The dry friction turns into lubricated friction.

Credits: p. 47 Laurie Skating, Barney Moss, CC BY (Flickr); p. 48 Curling, Peter Miller, CC BY-NC-ND 2.0 (Flickr); p. 49 Sparks, Przemek Pietrak, CC BY 2.0 (flickr), p.50 Rosle Cheese Grater, Didriks, CC BY 2.0 (Flickr)

Appendix 1. Two books

1. Put two sheets of paper on top of each other on the table. Pull the top sheet parallel to the table.

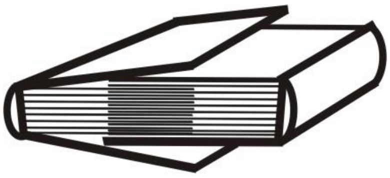
Observation

- *What happens to the bottom sheet of paper when you pull the top sheet of paper parallel to the table?*
- *Do you feel any resistance as you pull the top page?*

2. Put one sheet of paper on top of another on the table and one of the books on top of them. Try to pull out a sheet of paper between the book and the other sheet of paper.

Observation

- *Is it easy to pull a single sheet of paper out from under a book?*



3. Turn the pages of both books one after the other - so that the books are stuck together in this way. It is important that the first sheet of the first book is on the first sheet of the second book, and that the second sheet of the first book, and so on.
4. Firmly grasp the spine of one book with both hands and have the other person grasp the spine of the other book with both hands. On a common signal, pull the books together, trying to separate them. Do not pick up single pages!

Observation

- *Is it easy to separate the two books clamped into each other? Why?*

Credits: This page - own work (D. Sokołowska)

Co-funded by the
Erasmus+ Programme
of the European Union

How Much Can an Aluminum Boat Carry?

Teacher Guide

Mojca Čepič
Ana Gostinčar Blagotinšek

Guided inquiry (competition)

Introduction

Students are asked to design a boat from a piece of aluminum foil that carries the heaviest cargo. This activity could be used as a brainstorming before considering buoyancy. The activity is designed as a competition, and it has a strong motivating potential because of that.

The activity has a rich potential for extension to other topics, for example, surface tension, equilibrium of floating bodies, average density, or even to theoretical consideration as finding extrema.

Curriculum topics

It can be used as a brainstorming in physics lessons about:

- Buoyancy
- Measuring procedure
- Density and average density

Its extensions can form independent inquiry-based learning units on

- Surface tension
- Free energy
- Equilibrium of floating bodies
- Finding extrema theoretically

No ICT tools are needed. If objects used for cargo differ from one student to another, kitchen scale is handy.

IBL level

The module is embedded into the IBL cycle at the level of guided inquiry. However, the suggested use of competition is in the first brainstorming part of the IBL cycle as it strongly fosters motivation. An extension to the open inquiry level is possible. Students can study effects of surface tension, distribution of the load, different shapes of aluminum foil as a starting material.

Age of students

Competition is appropriate already from the elementary level to lower and upper secondary level, and university students and in-service teachers appreciated the potential richness of the task. Inquiry on effects of load distribution or/and surface tension can lead to a demanding project for lower or upper secondary school.

Practicalities

Materials

For COMPETITION

- Aluminum foil for preserving food in a roll.
- Ruler
- Pen, for writing on plastic, if possible.
- Scissors
- Tray with at least 5 cm high edges
- Beaker with water
- Paper towels
- Small equal objects like paperclips, coins
- Kitchen scale, if equal objects cannot be guaranteed for all participants.

For EXTENSION

- Dish soap
- Non-dissolvable plasticine
- Kitchen scale

ICT components

REMOTE.

A program that allows uploading photos and reporting conclusions, like *Google Jamboard* is necessary for the comparison of results and discussion within and between groups if worked remotely.

Grouping

Groups of 3-4 students are preferable. Two students or individuals are usually caught in one way of thinking; for more students, it is usually difficult to maintain motivation for all participants in the group.

Setting

CLASSROOM.

Nest arrangement of students' tables is advised. Tables should be as far apart as possible. Access to water and to paper towels is needed.

REMOTE.

For the initial introduction of the task students are in the main room. Materials should be checked. Rolls of aluminum foils in one country are very often of the same width. Nevertheless, width of the foils should be checked. If participants have different width, the narrowest foil is taken as a standard. For conducting experiments – students are put in breakout rooms randomly; notes are taken on the *Jamboard,* and each group takes a separate slide. Each group has to have at least one kitchen scale. If it happens that none of the participants in a group has a kitchen scale available, groups are rearranged so that in each group, one person has it at least.

Competition results are written to the shared main board.

The IBL (30 – 40 minutes)

Instructions (10 minutes)

Construct the boat from a piece of aluminum foil that carries the largest cargo.

Divide the width of the aluminum foil to three parts. Cut three equal squares from the foil. If students want to try more boats, they can cut more squares. There is no limitation in the number of trials.

In the classroom equal paperclips, a full box or even two boxes are provided for each group. An interesting alternative the lowest unit coins, for example 1 cent. However, the teacher has to collect those coins in advance for a longer time as the cargo can go up to 50 coins.

For the remote setting, using coins of any unit is advisable. However, encourage students to collect different appoena and a few of the smallest units at least for fine tuning. Also, paperclips could be used, or nails or drawing pins. But as one cannot guaranty equal cargo units in this way, participants that do not use coins need the kitchen scale. For the coins, masses are given. Below is an example for Euros.

Coin	2 €	1€	50 cents	20 cents	10 cents	5 cents	2 cents	1 cent
Mass [g]	8.50	7.50	7.80	5.74	4.10	3.92	3.06	2.30

Table 1: Masses of Euro coins.

At the beginning students try a few shapes, after a trial or two, the competition is stopped for a short break. Under remote conditions students are called to main room. Students agree on measuring the cargo.

Discussion on how to measure the cargo is left to students. They quickly come to agreement on the number of objects, if they all have equal objects, and to the mass of the objects, if objects differ. One of important rules that has to be decided is, which number gives the cargo, the number of objects before the boat sinks or after it. While for equal objects the difference between the two is not important as it usually differs for one object only, however, if one has to rely on mass, one additional object can have a different mass. Therefore, it is advisable that in both cases, number of objects or mass, the heaviest cargo means that the boat is still barely floating.

Competition (25 minutes)

After the mode of comparison of cargo is cleared and agreed upon, students return to their work, that is, to breakout rooms under emote conditions. They write their cargos in their notes or to the *Jamboard* and report the teacher when they have a new and improved result. The teacher writes the cargos to the white (main) board.

After approximately 30 minutes, might be 10 minutes more when students are very persistent, the best cargo does not increase anymore. At this point the competitions stops and the winning group is announced.

End of competition and new inquiries (5-10 minutes)

When winners are known, there is time for reflection. The shapes of winning boats and non-winning boats are compared, and conditions for floating and sinking are discussed based on students' experience.

The shape of the boat is important, but we have not figured out (yet) if the most popular and successful shape is also an ultimate best shape. Archimedes law says that the weight of replaced water is equal to buoyancy. So, intuitively, to allow for the heaviest cargo, the immersed volume should be the largest possible for the boat. Here, the shape of the virgin foil poses severe limitations; not every shape is possible.

In addition, the shape has to allow the positioning of the load in such a way that the whole boat is stable. Surprisingly, oval shapes are not good as they easily overturn. The best shape, as turned out, is very simple, a square-shaped bottom with low edges. This shape allows for spreading the load, which stabilizes the cargo. Surprisingly, also cylindrical shapes with low edges are good because they are very stable in spite of lesser volume. However, they rarely win under described conditions. The effect of load distribution is easier studied with plasticine remodeled in sheets than by placing objects.

Also, the foil without edges carries significant cargo, however, relatively low edges are the best. If one studies how the height of the edge influences the boat's potential for the cargo, it is easily realized that dependence is not linear, and it has to have a maximum. At the high school and university levels, the problem can be analyzed theoretically, although calculations show that there is a gap between theoretical predictions and real outcomes, which opens the door to the discussion of modelling and approximations.

Surface tension is also important for this experiment and makes a significant difference between the winning number of coins and the shape in the pure water or the water with reduced surface tension with liquid soap. Studying the effects of surface tension could be a stimulative open inquiry or even a student's project.

Physics behind

As floating and sinking are usually taught together with density and buoyancy, let us repeat some physics background, students preliminary concepts and how to assess them.

Density is a property of a point in the space and can vary with position. One calls it an intensive quantity with a scalar nature.

$$\rho(\vec{r}) = \frac{dm}{dV} \tag{1}$$

However, in teaching chemistry, one often talks about the density of materials, and the density is the characteristic material property that could be used for identification of the material. In teaching physics, one often talks about the density of objects, both, homogeneous and inhomogeneous. For the latter, the average density is the property of the object and is neither intensive, the property of the space, nor extensive or additive, the property that increases if more objects are considered together, like mass.

The average density is defined as

$$\rho = \frac{m}{V} \tag{2}$$

where m is the total mass of the objects and V is its total volume. Here it is important what is considered as a „total" for an object. For example, the boat that includes the air and the coins has a different volume as the boat that excludes the air. Also, a comparison of the average density of the boat and the liquid, that is, water, is different. If one wants to compare the density of the boat and the coins without the air, the boat should be put in the water, the water should replace the air in the boat, and the boat, obviously, sinks indicating that its average density is larger than that of water. On the contrary, if the air is considered a part of the boat, it should remain in the boat during the floating test, and the boat has to be put onto the water surface.

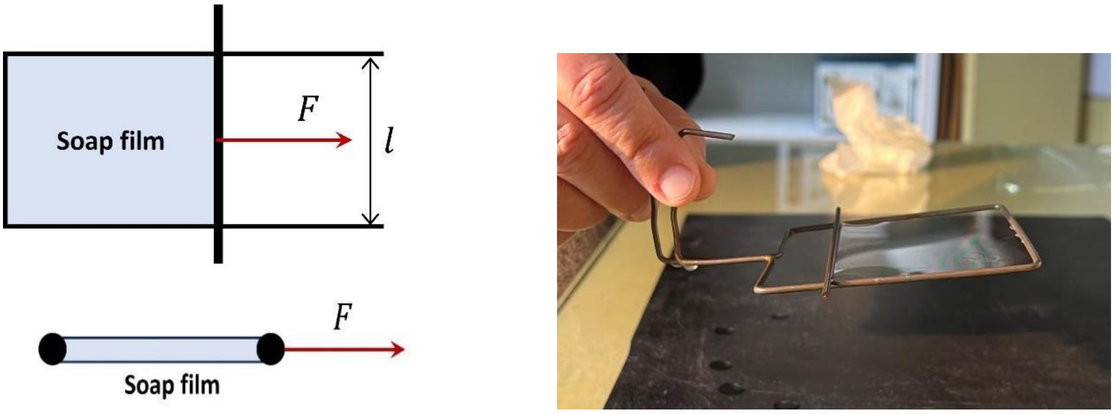
So, the definition of the object, which average density is of interest, also defines the floating test procedure for the comparison of densities.

Another aspect that is important for smaller and lighter objects is surface tension. In some curricula, it is introduced or mentioned at least as a force that depends on the length of the line, where three materials meet, for example, water, glass, and air. In contrast to elastic force, which depends on the extension of an elastic membrane, the origin of the surface tension is the force needed to pull molecules from the inside of the liquid to the surface and is independent of the size of the surface.

$$F = \gamma \, l \tag{3}$$

Here, F is the force of surface tension, γ is characteristic constant of the two materials in contact, and l is the length of the line, where the third material comes in contact. So, phenomena originating in surface tension are seen near those contact lines, for example, at the contact of water, glass, and air, we see meniscus.

However, surface tension is associated to the energy. Let us calculate the work done by increasing the surface of the soap in a very simple experiment usually used in demonstrations.



(a) (b)

Fot. 1: Demonstration of surface tension effects; (a) bird view above and side view below. Length of the soap-crossbar contact l, and the surface tension force F. Note that there are two contact lines to the crossbar. (b) Demonstration. The frame is tilted, and weight of the crossbar levels the surface tension.

By pulling the crossbar with a constant force equal to the force of surface tension, work A is done on the soap film and its energy increases. For the shift of the crossbar for Δx , the work A is

$$A \ = 2\,\gamma\, l\, \Delta x \ = 2\,\gamma\, \Delta S \qquad (4)$$

Which is directly proportional to the increase of the surface $\Delta S = l\,\Delta x$. The factor of 2 has to be included, because there are two lines of contact between the soap film and crossbar, one below and one above. It makes sense, the number of molecules that were moved from the inside of the liquid to the surface and are now in contact with air or some other material is directly proportional to the increase of surface ΔS . One can easily introduce a form of energy associated to surfaces as surface energy W_S

$$W_S \ = \ \gamma\, S\,. \qquad (5)$$

Now, we can consider the whole problem of a boat as or other problems where surface tension effects are not negligible, in a different way. The mechanical energy of the system, the water, on which the boat is floating, and the boat with its cargo should be minimal. To this energy contributes the potential energy of the boat, the potential energy of the water and the surface energy of the contact area of aluminum and water and the surface of the water air contact. We can neglect the aluminum air contact surfaces. We cannot calculate, but we can at least understand the role of surface tension. The potential energy of the boat decreases, because it sinks to the water, the potential energy of water increases, because displaced water is moved upward to the surface. The aluminum foil has a surface energy of the contact of water and aluminum, which depends on the surface of this contact, and finally, we can observe, that before the boat sinks, the water surface is rounded around the boat, so the surface area of the contact of water and air increases. The sum of changes in energy of all these contributions should be negative if compared to the same boat just above the water. Even more, the sum of this changes should be maximal and the mechanical energy of the system in equilibrium minimal.

The energy consideration is usually avoided as the energy is understandable in simple systems. However, for more talented students, consideration from the point of energy in such complicated systems as in the boat competition may open another perspective on several problems. Here one has to mention that it is probably impossible to calculate energies and obtain theoretical expressions that allow for predictions. But, the whole problem with surface tension leads to an interesting open inquiry or a project, which requires systematic observation of floating and inquiry of floating conditions.

Conclusions

This activity with its competition character using easily accessible materials can be used with a various goals. It can be used as a brainstorming in inquiries related to density and buoyancy. It can also be used for introduction to measurement and raising awareness that in order to compare measuring results, the measuring procedure has to be well defined. Finally, as activity is very simple, it can be used even in primary levels of education, however adding complexity, reducing instructions and raising awareness of phenomena that are not evident in the first moment, the activity can be implemented at all levels of education including university.

References

Surface tension is an interesting phenomenon, but often misunderstood and very often falsely explained, even in textbooks. The paper suggested below is very illuminating and suggested for reading.

M V Berry (1971). The molecular mechanism of surface tension *Phys. Educ.* **6** 79.
https://doi.org/10.1088/0031-9120/6/2/001

Credits: pp. 55, 56 & 61, own work (M. Cepic)

Co-funded by the
Erasmus+ Programme
of the European Union

How firm is my bridge?

Teacher Guide

Mojca Čepič
Ana Gostinčar Blagotinšek

Guided inquiry (competition)

Introduction

Paper as a material is not considered a proper material for building bridges or constructions that carry loads. However, if the paper is shaped properly, the structure could be elastic, the structure could carry the load, the structure does not bend, etc. There is a whole science studying properties of materials in sheet forms, which have intentionally manipulated structures that influence various properties of new objects formed. The Bridge activity is an example that demonstrates enormous changes of properties of paper if its shape is manipulated.

This activity could be used as a brainstorming before considering the measuring procedures in general. The activity is designed as a competition, and it has a strong motivating potential because of that.

The activity has a rich potential for extension to an open inquiry, to search for the ultimate best shape of the bridge, to analyze how the distribution of the load increases the strength of the bridge, and finally, how different materials in sheet forms can act as bridges and what are their limitations for structures.

Curriculum topics

It can be used as a brainstorming in physics lessons about the measuring procedure. Its extensions can lead to open inquiries about material properties as mentioned above.

IBL level

The module is embedded into the IBL cycle at the level of guided inquiry. However, the suggested use of competition could be placed in the brainstorming part of the IBL cycle as it strongly fosters motivation. In the continuation, a measuring procedure in general is discussed. This topic, measurements of length, volume, time, mass, and temperature, is usually considered as boring and obvious. However, realization that a firm agreement on any measuring procedure is necessary, is introduced by comparison of the firmness of the bridge, which is the property that does not have an established measuring procedure and has to be agreed upon by participants of the competition.
An extension to the open inquiry or even to the longer and more demanding inquiry project is possible.

Age of students

The activity is appropriate already from the elementary level to lower and upper secondary level, and university students and in-service teachers appreciated the potential richness of the task.
Inquiry on effects of the shape of the paper, that is, how to fold or manipulate in other ways the paper influences the firmness of the bridge and its ability to carry the load.

Practicalities

Materials

For COMPETITION

- Several 5g papers size A4
- Support like two piles of books, two tables of equal height, two equal chairs or similar.
- Ruler
- Adhesive tape
- Scissors
- Various objects, which serve as weighs.
- Kitchen scale

For EXTENSION

- Transparencies
- Other materials in forms of sheets

ICT components

No ICT is needed for experimenting in person. However, a program that allows uploading photos and reporting conclusions like Google Jam Board is necessary for comparison of results and discussion within and between groups if worked remotely.

Grouping

Groups of 3-4 students are preferable. Two students or individuals are usually caught in one way of thinking, for more students is usually difficult to maintain motivation for all participants in the group.

Setting

CLASSROOM.

If the activity is carried out in the classroom in person, it is advisable that each group of students can use two tables as supports. Groups should be as far apart as possible to prevent copying the solutions as its opportunity suppresses creativity.

REMOTE.

For the initial introduction of the task students are in the main room. Materials should be checked if they are appropriate for the task.

For conducting experiments – students are put in breakout rooms randomly, notes are taken on the *Jamboard,* each group takes a separate slide and adds new ones if needed. Each group has to have at least one kitchen scale. In this way, a student without a kitchen scale can still carry out the inquiry semi quantitatively and finds better and better papers profiles for the bridge, but the ultimate test of the shape is finally done by the student, who has the kitchen scale following the instructions how to fold or shape the paper profile.

If it happens that none of participants in a group has a kitchen scale available, groups are rearranged, so that in each group one person have it at least.

Competition results are evidenced on *Jamboards*. Profiles of bridges are photographed before they are destroyed by loads, during the loading, when they still carry the load, and the final two loads, the one before the bridge collapses and the one after the bridge collapses are noted and are both considered as a final result for a specific profile of the bridge.

The competition (30 to 40 minutes)

PART 1.Instructions (15 minutes)

The instructions take place in the main room. If the activity is carried out in person, students are divided to groups randomly in advance, if the activity is carried out remotely, distribution to groups is done after introductory instructions.

Instructions are given in a general way. Students are told that their task is to construct a bridge from one A4 sized paper that can carry the load. How they want to do it, is left to them. The bridge should span over 26 cm wide opening between the two supports. The width of the A4 paper is 21 cm, and the length is 29.7 cm. Supports, that is, two tables, or two piles of books or two chairs etc. have to be properly positioned before students start to shape their bridges. The teacher has to inspect and the students have to demonstrate by ruler that their supports are properly positioned. The paper profiles for the bridges can be fixed with an adhesive tape but only at the edges in the width of a small adhesive tape (around one cm).

Next, students in groups or, if remote, individually, start working. The teachers inspect the work in the groups but does not comment on ways of measuring the load. The adhesive tape can be used at edges of paper bridges to fix the shape but across the whole construction of the bridge.

After each group constructed at least one bridge and it reported it on the Jamboard in remote conditions, the teachers invites all students to discuss, which profiles they used and what was the load the bridges carried. Next, groups have to describe, how they measured the load. There are several ways to measure it. It can be put the load on the bridge, but not all shapes allow that. The load can be hung on the bridge, but where, at the sides, at several points, in the middle? The teacher reminds the students that they are building the bridge, which means that the bridge have to carry the whole load at all its places.

Finally, the students have to agree about the measuring procedure, that is, about the placement of the load, how to place it, with string for example or with a strip of defined width, and they have to agree on the measure of the firmness of the bridge, which is usually expressed in grams of the load.

Competition (20 - 25 minutes)

After the measuring procedure for the “firmness” of the bridge is agreed upon, students return to groups and start finding better, more firm profiles of paper bridges. When the group has a promising result, students can report it immediately, as finding the best bridge is a competition between groups. On the other hand, motivation of other groups increases if students think they can beat the best result. If all class becomes familiar with the profile of the good bridge, which is easy in in-person setting, but has to be encouraged by uploaded photos in remote setting, is this additional motivation to find even better shapes. However, the openly accessible shapes might also suppress the creativity, as it often happens that the whole class starts to improve one shape of the profile and do not consider other possibilities at all. If this happens with an accordeon profi, the teacher may encourage the students with telling them that he has heard about loads close to 1 kg. In fact, the optimal profile is cylindrical, and we were present when the load surpassed 1 kg, so this is not a joke.

End of competition and new inquiries (5-10 minutes)

When the highest load, that is, the firmness of the best bridge does not change for a while and usually students loose interest for improving the shape of the profile or trying new profiles, the competition is finished and the winning group is announced.

There are several possibilities to continue the inquiry. One can consider the effects of the measuring procedure on the result, for example, using an wider stripe, which introduces the concept of pressure or narrower supports, where the bridge is not supported by a horizontal flat surface. One can even check if different measuring procedure changes the order of best bridges or not. Different materials for bridges can be used, old transparencies for example. One can also study the effect of the length of the bridge by changing the distance between supports, which can be used before introduction of the concept of torque.

Finally, different shapes of different profiles are widely used in construction. Even in shops with furniture for depos one can easily find different profiles used for different shelves that may carry different loads. So, the shape of the profile matters, it matters a lot. One can also allow to use two papers, which on the other hand allows for putting objects on the bridge but still test cylindrical and similar shapes of profiles. One of in-service teachers from our PLCT suggested to use a catenoidal profile, which is the task remained to perform.

Physics behind

This activity is an outliner to regular school activities, but nevertheless, its most important message is that to make a fair comparison of properties, one has to agree on a measuring procedure.
Students have to agree on equal “firmness”, which means, that two bridges carry the same load.
Students have to agree on larger or smaller “firmness”, which means, that firmer bridge carries larger load. To define the number to the firmness, the loads have to put on scale and their weight should be measured. But the whole problem is not in these three steps, which are obvious, but in agreement on position of the load, if it is put on the bridge, which excludes several profiles, or it is hung from below. If the load is hung, the best way is to make a paper basket or a sling with the same width of the stripe that goes around the bridge for everybody.

Conclusions

This activity with its competition character using easily accessible materials can be used with various goals. It can be used as a brainstorming in inquiries related to measurement, for introduction to measurement and raising awareness that in order to compare measuring results, the measuring procedure has to be well defined. In its extended form can be used for introduction to concepts of pressure and torque. Finally, as activity is very simple, it can be used even in primary levels of education for observation and -measuring skills, however adding complexity, reducing instructions and raising awareness of phenomena that are not evident in the first moment, the activity can be implemented at all levels of education including university.

Credits: pp. 63 & 64, own work (M. Cepic)

Co-funded by the
Erasmus+ Programme
of the European Union

Building towers

Teacher Guide

Reinout Putman

Guided inquiry (competition)

Introduction

When we were children, we all built towers. But we may not have thought about how to make our tower as tall as possible. In this workshop we will change that.

We look at the relationship between the center of gravity and equilibrium and how triangulation makes it possible to build more strong buildings.

Curriculum topics

It can be used as an introduction in physics lessons about:

- Balance
- Strength

IBL level

The module is embedded into the IBL cycle at the level of guided inquiry. The teacher explains the experiment to the students, but the students work out how to make the tower on their own. It is recommended to conduct this workshop with larger groups divided into smaller groups. This approach allows students to conduct research using different methodologies and analyze and compare their findings.

Age of students

This workshop is possible starting from the elementary level to lower and upper secondary level, and university students and in-service teachers. The only requirement is that the group is fairly homogeneous in terms of technical prior knowledge. If not, the competition that’s included in the workshop won’t be very fair.

Practicalities

Materials

CLASSROOM.

Each group should take the following materials:

- 2 packs of plain spaghetti, 2 bags of marshmallows (may be expired)
- Or a more sustainable alternative: straws or sticks (best bamboo) with stretchers.

For each workshop, you need at least:

- 2 folding rulers
- 1 fan

REMOTE.

Each participant should take the following things:

- 1 pack of plain spaghetti, 1 bag of marshmallows (may be expired)
- folding ruler
- fan

ICT components (app installation and testing)

CLASSROOM.

No ICT is needed for experimenting in person.

REMOTE.

First of all, you need a program to call each other and to make breakout rooms like Teams or Zoom. A program that allows uploading photos and reporting conclusions like Google Jam Board or Mural is necessary for comparison of results and discussion within and between groups if worked remotely

Grouping

CLASSROOM.

If you conduct the workshop in a normal classroom, you can create groups of 3 to 5 students.

REMOTE.

If all the students have the necessary materials, they can all work individually. If that’s not the case they can be with 2 in one breakout room where one person supports the builder.

Setting

CLASSROOM.

Give students as much space as possible. Move all benches and chairs aside so that there is as much free space as possible.

REMOTE.

For the initial introduction of the task students are in the main room. Materials should be checked. For conducting experiments – students are put in breakout rooms randomly, notes are taken on the *Jamboard or Mural* each group takes a separate slide.

IBL unit (60 min)

Instructions (1 min)

Without providing excessive detail, the facilitator instructs the participants to construct the tallest tower feasible, starting from ground level. They are permitted to use all of the materials provided to them.

PART 1. Competition – part 1 (20 min)

The participants start to build their towers. if possible a large clock displays a countdown. If you have a beamer available or you work online, you can use this one, for example: https://www.online-stopwatch.com/countdown-timer/

Instructions and comparison (5 min)

In the initial segment of this intermediate phase, the teams or individual participants will assess the height of their tower and produce an intermediate score. While reviewing the towers, the discussion may cover these points:

- By employing triangles, more robust structures are often constructed.
- An object maintains its balance when its center of gravity is precisely above or below the axis on which the object is situated (the fulcrum). So, it is advisable to widen the fulcrum to increase the likelihood of the center of mass being above it.

PART 2. Competition - part 2 (10 min)

Participants will receive an additional 20 minutes to refine their design after reviewing the content. However, they will be faced with an additional challenge in which a fan will simulate a breeze to test the stability of their design. If the workshop takes place in a classroom, the fan will be positioned to create a wind that is most prevalent in the country. For instance, in Belgium, a brisk south-west to west wind is the most common.

Conclusions

This activity with its competition character using easily accessible materials can be used with various goals. It can be used for technical or physics education. The emphasis can also be on creativity. A variation could then also be made, for example, where a shelter has to be made for rain at different heights. Finally, as activity is very simple, it can be used even in primary levels of education, however adding complexity, reducing instructions and raising awareness of phenomena can be implemented at all levels of education including university.

Physics behind

Triangulation

A truss, a structure composed of triangles, is employed in structural and civil engineering to provide a spanning capability (usually using steel). Truss bridges and roof supports are common applications. In audiovisual technology, this typically aluminum framework is known as a truss.

The load on the truss is absorbed only by tensile and compressive forces at the nodes, which are treated as hinged for the purpose of calculation, with no bending assumed.

For a truss comprising n nodes and m bars, the equation $m = 2 - n - 3$ holds true.

This relationship is applicable to triangular trusses, which are inherently stable thanks to their dimensional rigidity, enabling them to provide structural stability.

Balance

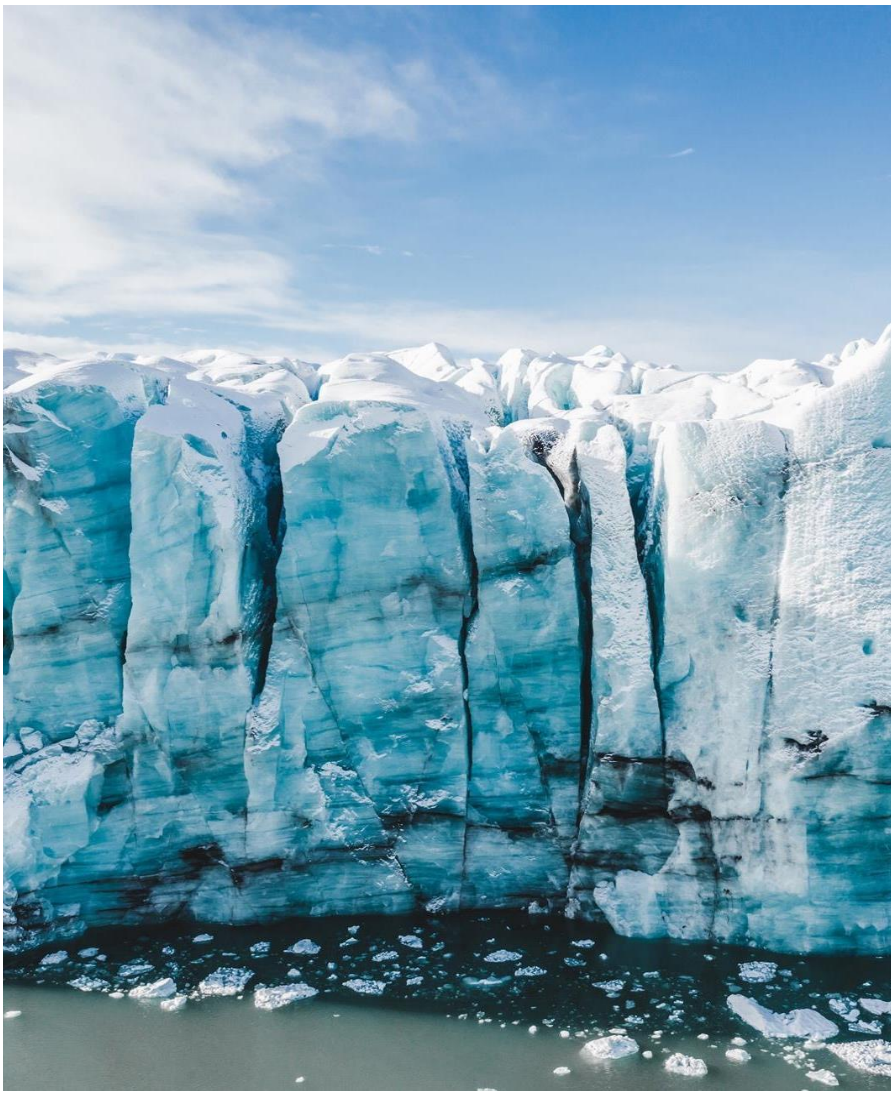
There are three types of balance:

1. The centre of gravity is below the fulcrum. We then speak of **stable equilibrium.** If the object is unbalanced, it returns to its original position by itself.
2. The centre of gravity is above the fulcrum. The equilibrium is then **unstable**. If the object is now thrown out of balance, it will fall further out of balance.
3. The centre of gravity coincides with the fulcrum. We then call the equilibrium **indifferent.** Unbalancing the object will not result in any further movement.

Credits: p. 71 Eiffel Tower, Matheus Albuquerque, Free Stock Photo, Pexels

Co-funded by the
Erasmus+ Programme
of the European Union

Melting Ice Cubes



Teacher Guide

James Lovatt

Paul Grimes

Eilish McLoughlin

Guided and open inquiry

Introduction

This unit aims to introduce the learners to the concept of density. In particular, this will focus on density in liquids, however, extensions are proposed to extend the activity to density in gases. In addition to the science concepts being explored, learners should also have opportunities to generate ideas, make predictions, interpret experimental data, draw conclusions, and present results. There is a strong focus on supporting learners to articulate their reasoning through writing causal explanations and visual representations.

Curriculum topics

It can be used in science lessons about:

- density of liquids
- particulate nature of matter
- density of gases (extension activity)

During classes, students use low-cost materials easy to find at home. Measurements are taken using thermometers and through learner observation.

IBL level

The module is embedded into the IBL cycle at the level of guided inquiry. It can be adapted for open inquiry depending on learners' previous experience of inquiry. An extension to the open inquiry level is possible.

Age of students

It is suggested that this activity can be completed with lower secondary students (12-15yo). The experimental tasks could be done with upper primary students (11-12yo) however, it's not anticipated that they would be able to complete the reasoning and modelling tasks at the level expected.

Practicalities

Materials

PART 1.

- A3 worksheets for students to write their initial predictions and reasoning

PARTS 2 and 3.

Equipment list per group

- A3 worksheets from part 1, updated to include modelling stages (see unit description for more detail)
- Hot water
- 2 x Thermometers
- Clear and blue dyed ice cubes (2 of each)
- 4 x 100mL or 250mL Beakers or clear drinking glasses (to melt ice in)
- Salt (to make salt water)
- 2 x Spoons
- Trough or basin to collect spills
- Blue and red food dye to dye hot and cold water
- 2 x Glass Jars (or alternative) - need to be same shape and size so can place on top of one another
- Laminated Card / Hard plastic sheet to separate jars before mixing
- Post-it notes.

PART 4. Extension Activity

- Matches
- 3 candles cut to different lengths.
- Blu-tac
- Bell-Jar or 2L Beaker (to cover candles)

ICT component

ICT is not an essential component of this unit for in-person teaching. It can be used to display images and tasks via PowerPoint. If teaching this unit remotely, *Jamboard* can be used to replace the A3 sheets.

Grouping

Pairs or groups of three are preferrable.

Setting

CLASSROOM.

This unit can be completed in a classroom with advanced preparation. A laboratory is preferrable as hot and cold water is required.

REMOTE.

This unit can be taught remotely. Group experimental design and completion of experimental tasks can be completed in breakout rooms. Main discussion and collating of ideas should be conducted in the main room. *Jamboard* should be used to record group and experimental work conducted in breakout rooms. The teacher can monitor group progress by view the Jamboards and going to each breakout room.

IBL unit

The unit is described below. The timings provided are estimates based on a class group that has some experience of inquiry and causal explanations. They also assume Part 3 is being instructed as a teacher demonstration. The timings will need to be adjusted depending on students' prior experience and if a decision is made to require students complete the experiments in Part 3.

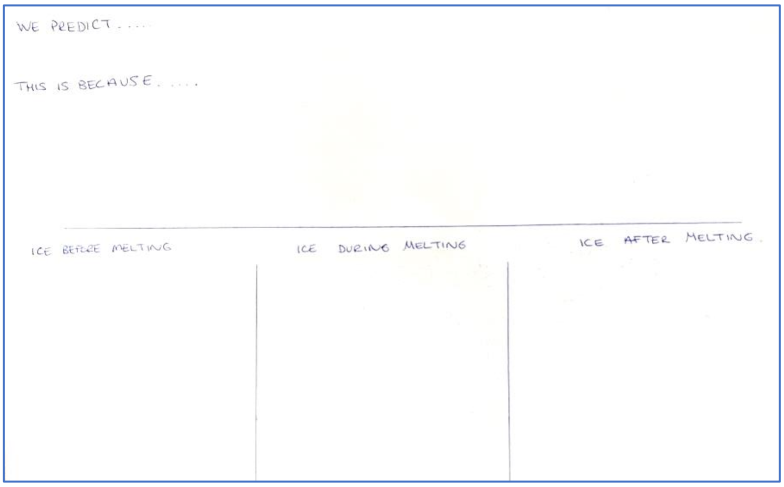
PART 1. Opening inquiry challenge (15 min)

The opening inquiry challenge is used as a hook to gain students attention. It is also used to get students to reason about prior knowledge and make claims and predictions. Students are required to write causal explanations to justify their predictions. The action of writing this explanation pushes students to think deeply about their claims and prior knowledge.

Causal Explanations are descriptions or storylines indicating ***why*** observable events happen. They require students to brainstorm and reason and explain their observations of events or processes where the factors causing the phenomenon are often abstract or unobservable. In this unit the observable event is melting of ice cubes in fresh and salt water. The concept relates to changing densities associated with water saturation and heating of liquids. Causal explanations can be produced as written text, process drawings, physical models. In this unit, students will use a mix of written text and process drawings. Causal explanations move beyond descriptions of what happened, they require students to reason and provide 'why' explanations for their observations. This helps to make students' thinking visible and allows for enhanced teacher questioning of student understanding. The process drawings used in this unit are a form of **Modelling** where students make their ideas visible. In this situation students have to use drawings to show their understanding of the particulate nature of matter to explain density changes. The teacher should support students to brainstorm about their experiences of melting ice to help them think about different ideas they have and to motivate them to engage in the inquiry.

To learn more about causal explanations and modelling it's highly recommended to read

Windschitl, M., Thompson, J. and Braaten, M., 2020. *Ambitious science teaching*. Harvard Education Press.



WE PREDICT.....

THIS IS BECAUSE......

ICE BEFORE MELTING

ICE DURING MELTING

ICE AFTER MELTING.

1. The teacher poses the inquiry challenge – will an ice cube melt faster in freshwater or saltwater? Students should first think about the question on their own. They should write down their initial ideas. The teacher can collect student ideas 'without judgement or confirmation'. The teacher can summarize student ideas and note any possible contradictory responses. In this situation, students will often mention freezing icecaps and putting salt on the road to 'melt' ice. The teacher shouldn't correct students' ideas at this stage.
2. Students are divided into their groups of 2 or 3 persons. They are given their A3 worksheet. Each group is asked to write their initial prediction and initial causal explanation for their prediction

PART 2. Experiment design and reasoning (45 min)

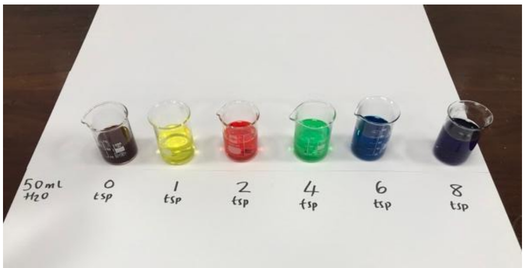
In this part of the IBL unit students design an experiment to test their predictions and use their experimental observations to update their causal explanations.

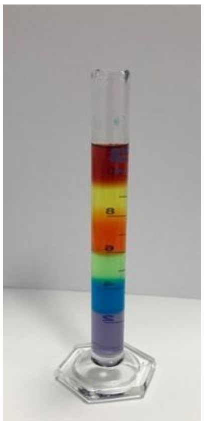
1. Each group is given 5 minutes to propose how they will test their hypothesis. Note, students are not informed about having blue ice-cubes at this stage.
2. Students complete their initial experiment and are asked to compare with their predictions. The teacher circulates and asks questions about fair testing and pushes students to make observations and take temperature readings. It's often the case that students predict that salt-water will melt more quickly, and they are amazed when they see the opposite. Some try to reason this against putting ice on footpaths and struggle to understand what is happening.
3. The teacher gives students coloured ice-cubes and asks them to repeat their experiment paying particular attention to the ice and any colour changes they observe. Students should notice the blue food dye resting on top of the salt-water and flowing down into the fresh water. At this stage students are asked to draw diagrams on their worksheet explaining what is happening at each stage of the task i.e., before melting, during melting and after melting.
4. They are asked to consider their observations and update their causal explanation

PART 3. Additional information… (45 min)

This part of the IBL unit aims to develop students reasoning skills. Additional experiments are used to provide more information that can be used to help explain their earlier observations. The idea here is that students learn to make conclusions from experiment observations. Note, depending on the time available to you, this part can be done as teacher demonstrations or student guided experiments. For this text, we will describe it as a teacher demonstration.

1. The teacher reminds students of the previous experiment and briefly discusses their different causal explanations and process diagram. The teacher explains that they will observe two more experiments that will give additional information that will help to confirm or challenge students reasoning and explanations for the melting ice cube experiment.
2. The teacher completes the first experiment. A glass jar of (tap) hot water coloured red is placed over a glass jar of (ice) cold water with a laminate sheet in between. The sheet is pulled slightly so the water can mix, however they will observe that they don't mix. At the same time the same apparatus is set up in which the cold water is placed above the hot water. In this situation the students will see that the cold water will mix down into the hot water. Students are asked to reflect on these experimental results and see if they help inform their understanding of the melting ice-cubes.
3. The teacher then demonstrates a second experiment. In this experiment, the teacher makes a density column with coloured solutions of different concentrations of sugar water. Once again students are asked to reflect on the experimental results to see if they help their understanding of the melting ice-cubes.
4. The students revisit their A3 worksheets and prepare their final causal explanation. They can use post-it notes to amend any diagrams or text.
5. A final discussion is held where the teacher explains the correct scientific reasoning. The teacher links this back to students' initial ideas about melting icecaps and putting salt on footpaths. These concepts are briefly explored in the context of the A reflective discussion is held on the process of making conclusions from observational data.





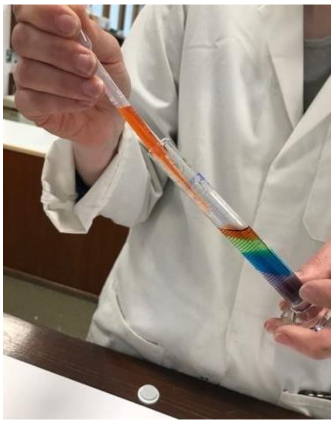
PART 4. Extension – Candles (guided inquiry, 30 min)

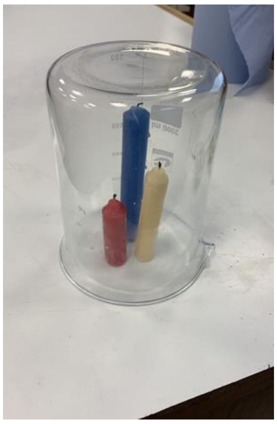
This part of the IBL unit aims to help students to make connections between density of liquids and density of gases.

1. This activity starts similarly to the melting-ice cubes. The teacher presents apparatus where three candles, cut to different heights are placed under a bell jar. Students are asked to predict which candle will go out first, second and third.
2. Students have to write their predictions and causal explanations. Students generally predict that the shortest candle will go out first and state it's because CO_2 is more dense than air.
3. The teacher carries out the experiment and they observe that the tallest candle goes out first followed by the middle height candle and then the shortest candle.
4. Students use their observations of the order in which candles go out to come up with a new causal explanation or add to their existing explanation.
5. The teacher provides a complete explanation linking to their understanding of the density of liquids observed in the melting ice-cubes activity and everyday examples such as hot-air balloons.

Closing by a teacher (5 min)

The teacher summarises the learning in the regard to both the scientific concept and IBL steps of making appropriate observations, modelling and drawing conclusions. The students have the opportunity to reflect and discuss their learning.





Science behind

PART 1.

When the ice is placed in the freshwater, the more dense cold water sinks to the bottom pushing up the room temperature water to the top in a circular motion thus melting the ice cube. In the saltwater example, the cold water is less dense than the salt water, thus it layers on top of the saltwater. In this scenario the water surrounding the ice is colder than in the freshwater example thus it takes longer to melt.

An alternative approach to teaching this concept has been produced by MIT can be found at the following link: https://blossoms.mit.edu/sites/default/files/video/guide/Ice-CubeMelt-Teacher-Guide.pdf This link also provides additional explanations of the concept

PART 2.

(a) this also links to the density of liquids. The hot water will be less dense than the cold water so will not mix if placed on top and will mix immediately if placed on the bottom. (b) The density column is made by placing the more dense mixtures in the bottom of the graduated cylinder. The more solute in the solution will make the solution more dense.

PART 3.

Oxygen is required for the candles to combust producing carbon dioxide. In normal conditions carbon dioxide is more dense than air so will sink to the bottom. In this case, the carbon dioxide is warm so it is less dense than air and will build up at the top of the container thus extinguishing the taller candle first.

Credits: pp. 73 & 74 Microsoft Word stock Images p. 76 Drawing of sample worksheet, own work (J.Lovatt); p. 77-79 Images taken from DCU experimental setup and workshop implementation, own work

Co-funded by the
Erasmus+ Programme
of the European Union

Earth rotation and rotation of water in sink

Teacher Guide

Ana Gostinčar Blagotinšek

Mojca Čepič

Guided & open inquiry

Introduction

This unit aims to challenge pupils critical thinking and verifying "facts" they find in various information sources (internet – YouTube in this case).

Curriculum topics

It can be used in physics lessons about:

- Circular motion and forces (Coriolis force)
- Motion in accelerated (non-inertial) frames of reference
- Critical thinking
- Experimenting with liquids

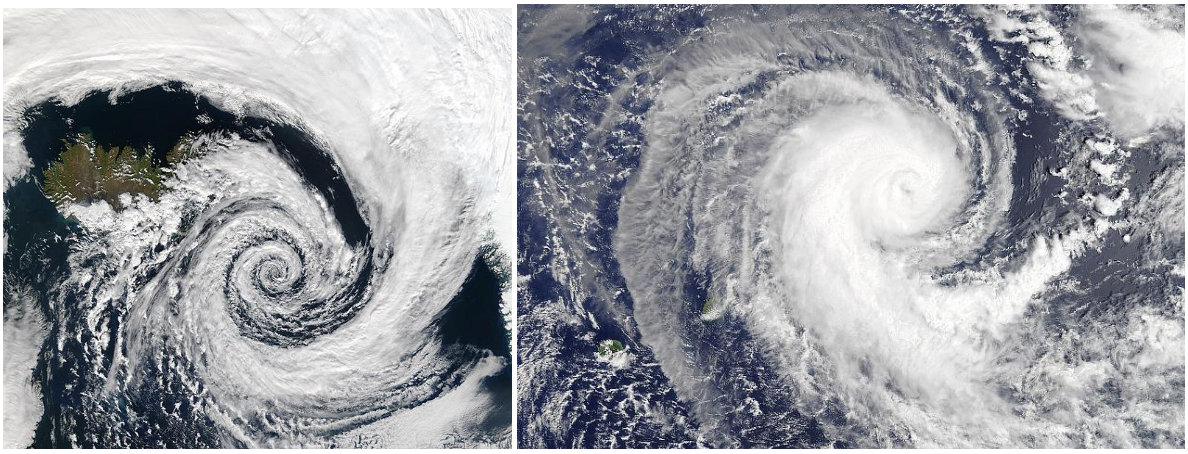
For the experiments students use items, easy to find at home. For viewing the initial video, a computer or smartphone with internet connection is necessary.

IBL level

The module is embedded into the IBL cycle at the level of guided inquiry, with possibility of an extension to the open inquiry. Students plan and conduct experiments to probe the claims in the video.

Age of students

As an exercise of critical thinking and "finding out by themselves" the unit can be used with 7-12 yo students, in lower secondary school and in a high school. As a study of Coriolis force effect, it is also applicable in a high school and at university level.



Practicalities

Materials

- video about water rotation on different hemispheres (type “equator line water test” in browser or visit https://www.youtube.com/watch?v=cLUXALnzSZI)
- a sink or
- a funnel and (large) bottle
- water
- a small piece of paper or vegetation
- computer and screen for video projection
- a smartphone for recording the experiments
- for further work or possible explanation see https://www.youtube.com/watch?v=aDorTBEhEtk

ICT component

A computer and screen are needed for video viewing in the classroom; students can watch it also on their smartphones. Smartphones are also handy for recording the results of experiments.

Grouping

Groups of 2-3 students are preferable; the task is also manageable for a single student.

Setting

CLASSROOM.

Nest arrangement of students’ tables is advised. Experiments are best done in the bathrooms (or any room with sinks). Students take notes in notebooks and record videos.

REMOTE.

For the brainstorming – students are in the main room. For conducting experiments – students in breakout rooms, taking photos or making video clips to record their observations.

IBL unit

Brainstorming (10-15 min)

The brainstorming aims to introduce learners to the topic by benefitting from their everyday knowledge and previous knowledge from physics or playground experiences. All students should be given the floor.

A storyline can be composed around:

Have you ever noticed water swirling out of the sink or a bathtub? In which direction it was rotating? Always in the same, in different, not at all?

or

Have you heard about cyclones, tornadoes and hurricanes swirling always in the same direction?

or any other topics which learners might have prior knowledge and experience with.

The purpose is to learn that:

- Earth rotation affects the motion of the airmasses, causing cyclones rotating in different (and always the same) directions on North and South hemisphere
- Optional: the Coriolis force, affecting movement of the moving objects in rotating frames of reference (Earth, carousel)

PART 1. Swirling water in the funnel (10 min)

At the end of the brainstorming video (https://www.youtube.com/watch?v=cLUXALnzSZI) claiming that Earth rotation also affects swirling of the water in sinks and funnels is shown to the students.

1. Students are asked about their opinion and reasoning about the content (is it feasible or not).
2. Students are asked to consider the reliability of the experiments in the video and the claims the presenter makes.
3. Students analyze the experiments shown in the video regarding the fairness of the experiments. What is done correctly, which are the questionable procedures?
4. Students are asked to plan an investigation to verify the validity of the claims in the video.

PART 2. Swirling direction on Northern hemisphere (20 min)

In this part of the IBL unit, students observe and investigate the direction in which water swirls in sinks and/or funnels (or even toilets).

1. Each group of students is either given a funnel and a bottle or access to sink.
2. Teacher asks groups of students to present their plans for investigation.
    - Students should realize that repeating the exact experiments from the video is not possible, but some information affirming or refuting the claims might be obtained without travelling across the Equator line. In large schools there might be enough sinks to provide statistically acceptable data on direction of water rotation (being different in different sinks and/or funnels at the same latitude) even without building a special experiment themselves.
3. Students in groups:

- discuss and put forward a hypothesis
- conduct the experiments with emphasis on fair testing
- record the results
- draw conclusions
- present their group findings to the class (last 5 min), videos might help as supporting evidence

4. For older, more advanced students teacher poses a question:
    - *What parameters determine the direction in which the water swirls when flowing through outlet of the sink/funnel?*
5. And proceed with the IBL cycle as above.

Closing by a teacher (5 min)

The teacher summarizes the findings and extends the lesson if needed.

Physics behind

Weather and air masses movement on Earth are indeed influenced by its rotation. Because of the Earth rotation air masses in cyclones (areas of low air pressure) rotate counterclockwise, and clockwise in anticyclones (areas of high air pressure) in Northern hemisphere. The situation is opposite in Southern hemisphere. Prevailing western direction of winds in Europe and Southeast direction of trade winds (in northern hemisphere) are also consequence of the Earth rotation.

The influence of the rotation of Earth on moving airmasses (and moving objects in general) is a well-known phenomenon, and the reason is a so-called Coriolis force. This is a fictious force, observed only in rotating frames, usually Earth. It forces bodies to the left in frames, rotating clockwise, and to the right in frames, rotating counterclockwise. Similar (fictious) is the centrifugal force, pushing object out of rotating carousels, or water from rotating centrifuge in washing machine.

Deflecting from straight-line movement can also be explained by noting that airmasses in different parts of the Earth initially move with Earth surface with different velocities; smaller at poles (because of the smaller radius of rotation) and with higher velocities at equator (with bigger radius of rotation). When airmass from pole travels towards equator, its velocity at some later position is smaller than the movement of the ground below it – so observer from the Earth sees it as following a curved trajectory, lagging behind (and similarly if observed from above earth surface, airmass is flowing along curved trajectory across Earth surface and not straight from the pole to the equator).

Students might have some experience with the phenomenon from carousels; if a person, sitting on a rotating plane pushes a ball outward, he sees it moving from him/her in a straight line; but the same movement observed from outside the carousel (from surrounding ground at rest) is seen as curved.

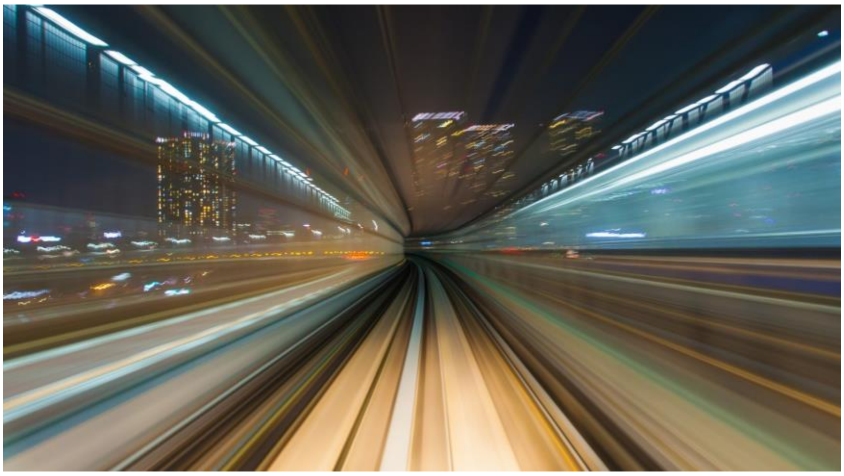
Earth rotation, however, is slow, and the Coriolis force relatively weak, so its consequences can only be observed in long-distance movements (like planetary airmasses movements). In everyday circumstances initial water movement, shape, and position of the outlet in the sink or funnel have much bigger and crucial impact. If we carefully remove all this factors, the Coriolis force's effect can be observed even on smaller scale (although not in a funnel or a sink); see https://www.youtube.com/watch?v=aDorTBEhEtk.

Credits: pp. 81 © Canva [2021]; p. 82 tropical storms over Northern (l) and Southern (r) hemisphere, Public Domain (NASA); p. 84 Water rotating different on different sides of Equator line, screengrabs from the cited video; p.85, experiments in sink and funnel, own work (A. Gostinčar Blagotinšek);

Co-funded by the
Erasmus+ Programme
of the European Union

RISE

Measuring Speed



Teacher Guide

Eilish McLoughlin
Paul Grimes
James Lovatt

Guided and open inquiry

Introduction

This unit was designed and implemented so that the teachers gain personal experience of open and guided inquiry activities. In this way, it was hoped that they gain a real appreciation of what their own students' experience was when completing IBL activities. This unit is concerned with the physical concepts of distance, time, the absolute value of velocity and its distinction from the concept of speed. The concept acceleration can also be included as an extension activity.

Curriculum topics

It can be used in physics lessons about:

- Measurement (accuracy of measurements) of distance and time
- Relationship between distance, time and speed.
- planning Investigations
- collecting and interpreting data
- drawing conclusions
- working collaboratively
- controlling variables

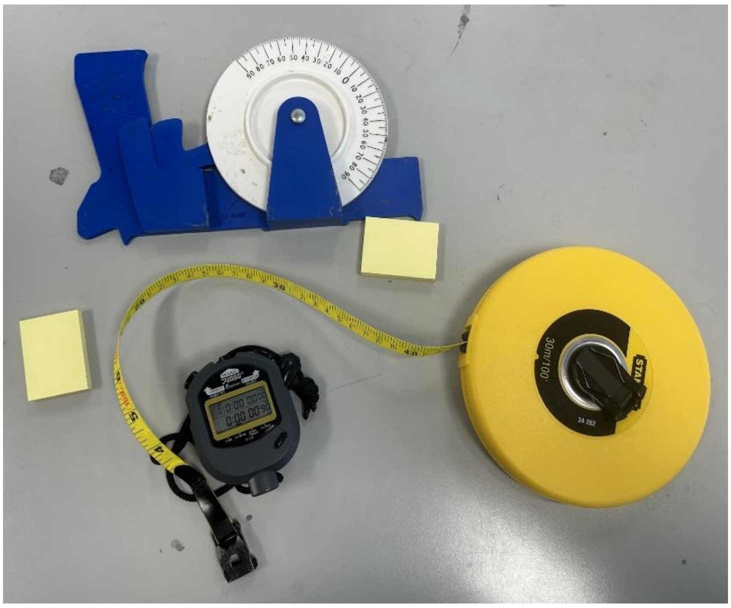
Students use basic materials to complete this experiment, e.g. measuring tape and timer. These materials are available in their homes so students can easily do this activity in the school lab or remotely.

IBL level

The unit introduces teachers to guided and open IBL activities and allows them to experience and compare teacher-led versus student-led approaches to several inquiry levels, including planning and carrying out investigations, interpreting data, and drawing conclusions. There are some proposed extension activities that are suitable as guided or structured inquiry activities.

Age of students

This unit is designed for lower secondary level (12-14 yo students). Velocity, and the term speed, are found in everyday life in relation to journeys and are of clear relevance to students. The extension activities could be adapted and used with upper secondary level if the focus of the activities addressed a more advanced understanding of the concepts of velocity and acceleration.



Practicalities

Materials

- Measuring tape or ruler
- Stopwatch or timer
- Tape, chalk, or object to mark specific distances on the floor.

ICT component

There is no specific ICT element for this unit. If you wish to extend this unit you could use a motion sensor to record motion and graphing software for data visualization.

Grouping

Small group work (2-3 students) is preferrable in this unit. Two students should engage in all tasks of the activity, while a third student acts in the role of an observer.

Setting

CLASSROOM/OUTSIDE SPACE.

Students should have ample space to be able to conduct this investigation and can use a corridor or an outside space to complete their investigations.

REMOTE.

For the whole group discussions all students should be in the main room. For conducting experiments – students should be facilitated in their groups in breakout rooms sharing their cameras to show they are doing. Worksheets could be shared as digital documents which students complete these activities so the teacher can monitor progress and ask different questions. Students can be encouraged to also complete their graphs on paper or using software such as MS Excel, Google Sheets, Vernier Graphical Analysis. They can copy and paste their results into the main digital worksheet. It's recommended the worksheets are shared with all at some point so they can compare their findings.

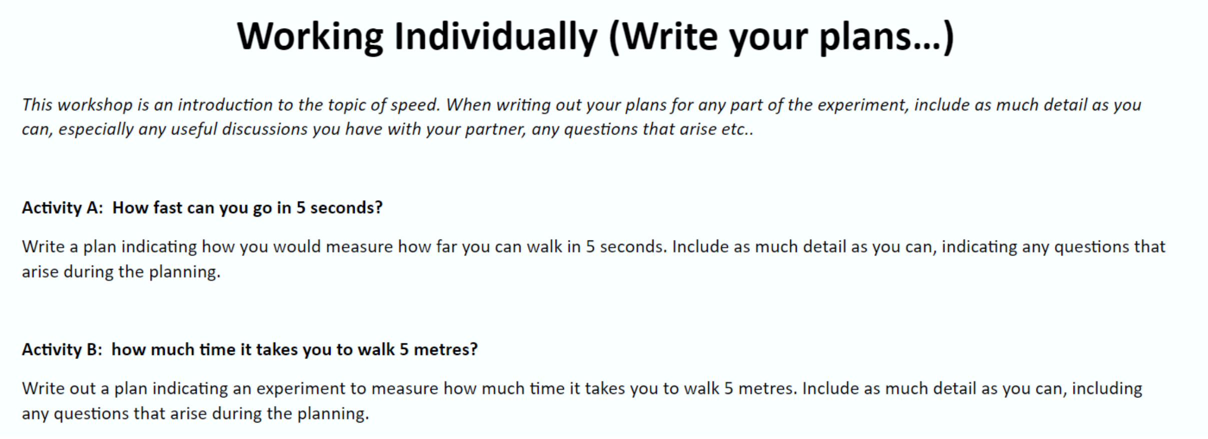
IBL unit

INTRODUCTION (10-15 mins)

Students write out a plan (working individually) for two investigations:

- Activity A: How fast can you walk in 5 seconds?
- Activity B: how much time does it take to walk 5 metres?

Working in pairs, students swap their plans with their peers and provide feedback on their peer's plans. Students update their own plans based on this feedback.



Working Individually (Write your plans...)

This workshop is an introduction to the topic of speed. When writing out your plans for any part of the experiment, include as much detail as you can, especially any useful discussions you have with your partner, any questions that arise etc..

Activity A: How fast can you go in 5 seconds?

Write a plan indicating how you would measure how far you can walk in 5 seconds. Include as much detail as you can, indicating any questions that arise during the planning.

Activity B: how much time it takes you to walk 5 metres?

Write out a plan indicating an experiment to measure how much time it takes you to walk 5 metres. Include as much detail as you can, including any questions that arise during the planning.

PART 1. Students carry out open inquiry investigations (30 min)

In this part of the IBL unit two students collaborate to complete their inquiry investigation according to their own written plan for activities A and B. They will investigate the influence of how far they walk and what time it takes to determine what their speed is. They should tabulate data and draw graphs to interpret their data and draw conclusions. A third student is assigned to observe the pair of students and pay close attention to how closely students execute their own written plans.

1. Students work in pairs to carry out their own plans for Activities A and B.
2. A third student is assigned to observe the pair of students and pay close attention to how closely students execute their own written plans.
3. The third student notes any problems encountered in carrying out the plan and any deviations from the written plans. The third student also notes how the pair collaborated to carry out their investigations.
4. The pair of students collate and share the findings of their inquiries, while the third student highlights what deviations are made to the original plan.
5. The pair of students reflect on their experience of planning and carrying out Activities A and B.

Speed: Inquiry

Carry out the Activities A and B.

Record measurements for both tasks below and write how you think the two activities are related.

How are distance and time related?

Remember to write any questions that arise during the activity.

Teachers should ask questions and guide students to develop their understanding of the relationship between distance, time and speed using the data and results presented by the students. Teacher feedback can highlight to students the importance of writing accurate and careful plans for their inquiry to ensure the findings of their inquiry are repeatable, reliable and reproducible. The teacher can identify and discuss different approaches groups used to record their results.

PART 2. Students carry out guided inquiry investigations (30 min)

This part of the IBL unit facilitates students to carry out two (guided inquiry) plans provided by the teacher to address the same inquiry questions:

- Activity A: How fast can you walk in 5 seconds?
- Activity B: how much time does it take to walk 5 metres?

Students use the same equipment as before. They should tabulate data and draw graphs to interpret their data and draw conclusions as per given plans.

1. Students are asked to carry out two (guided inquiry) plans provided by the teacher to address the same inquiry questions:
    - Activity A: How fast can you walk in 5 seconds?
    - Activity B: how much time does it take to walk 5 metres?
2. Students work in pairs to carry out these plans while a third student observes their inquiry and notes any deviations from the plans provided.
3. The pair of students collate and share the findings of this second inquiry and compare their results to those obtained in the first inquiry.
4. The third student in each group highlights what deviations (if any) had been made while students carry out the second plans.

Activity A: How fast can you walk in 5 seconds?

Work in pairs. Make sure you have a measuring tape, a stopwatch, masking tape, or a piece of chalk. One person (the walker) will walk at an even pace, while the other (the experimenter) will use the stopwatch to make measurements. At the end you will swap roles.

1) *Find a place where you can walk for about 10 metres.*
2) *If you're outside, use the chalk to draw a starting line. If you're inside, use the masking tape to mark the starting line on the floor.*
3) *Do a trial run of the experiment: The walker starts to walk at an even pace a small distance behind the starting line. The experimenter starts the stopwatch when the walker crosses the starting line, and tells the walker to stop when 5 seconds have passed.*
4) *If everything went fine, repeat what you did for your first measurement. Use chalk or masking tape to mark the place where the walker stopped.*
5) *Repeat the experiment two more times, so that you have three markings for places the walker stopped walking.*
6) *Label the marking closest to the starting line "X", the marking next closest to the starting line "Y", and the marking furthest from the starting line "Z". Measure the distance from the marking "X" to the starting line.*
7) *Measure the distance between lines X and Y and lines X and Z. Take the average of the two distances, and add this average to the value you found in question 6. Explain that this value is how far you walk on average in 5 seconds.*
8) *Swap roles.*
9) *Which of you two walks furthest in 5 seconds?*

Activity B: how much time does it take to walk 5 metres?

1) *Mark off a straight section 5 metres long.*
2) *Measure how long it takes for the walker to go through the section.*
3) *Repeat the experiment two more times.*
4) *Take the average of the three times.*
5) *Swap roles.*
6) *Which of you two takes longer to walk 5 metres? Which of you walks faster?*
7) *Discuss the methods of Activities A1 and A2 to compare speeds.*

PART 3. Comparing Open and Guided Inquiry Investigations (20 min)

Students are given the opportunity to reflect on their experiences of carrying out activities A and B according to their own plan and following the plan provided. Students are asked to consider what were differences in the the role of the teacher and student in the first 'open' inquiry approach and the second 'guided' inquiry approach. Teachers should prompt students to consider what scientific skills they have used while carrying out the first and second plans.

PART 4. Your journey to school (20 min)

Students work in groups of three to complete an activity to compare distance, speed and time taken for them to travel to school and consider differences between different modes of transport. This activity encourages students to consider the everyday example of their journey from home to school. They develop their skills of graphical representation of data by producing graphs to represent this journey by foot, bicycle, bus or car.

1. Working individually students are asked to complete a worksheet and fill in answers to the following questions:
   - How long does your journey to school take?
   - How far is the journey?
   - What method(s) of transport do you use?
2. Students are then asked to consider how changing mode of transport for the journey from home to school would affect their answers: "If you get to school in a car or in a bus, how long would it have taken you to walk..." a. at a comfortable speed, and b. at your fastest speed. A similar question can be asked for those who come by bicycle, whilst those who walk can be asked to estimate how long it might take by car. Give a complete explanation, and include calculations.
3. For any one of the results from parts 1 or 2 above, draw a graph of speed against time,
   a. Assuming uniform speed
   b. Representing what really happens?
4. Students are asked to consider what would the pair of graphs, one for walking and one for travelling by car or bus, have in common if both were drawn for the same journey? What does the area under each of these graphs represent?
5. For the graphs used in step 4, draw the corresponding pair of graphs of distance against time.

Activity C: Your journey to school.

Student 1:	Method(s) of transport	Journey distance	Journey time
Student 2:	Method(s) of transport	Journey distance	Journey time
Student 3:	Method(s) of transport	Journey distance	Journey time

Teachers prompt students to consider what would have changed or stayed the same if a different method of transport was used. Students are asked to provide complete explanations and calculations in their findings and record any observations or questions that they have while completing this activity. Teachers should encourage students to present their graphs to other students and "use their own words" to explain what is happening in each part of the graph. E.g. "*The slope is steeper in this part of the graph as I was traveling by car, compared to this part of the graph when I was walking on foot".*

PART 4. Extension Activities (20-90 min)

In this unit the focus was on facilitating students to plan and carry out several inquiry investigations and experience the difference between open and guided inquiry activities. Student artefacts (e.g. plans, data, graphs, results) can be collected as evidence of their skills of developing hypotheses (identifying questions), planning investigations (and carrying out research) and forming coherent arguments (evaluating conclusions).

These activities are adopted from the SAILS EU Project on Speed. It can be found online: http://sails-project.eu/units/speed.html

In the SAILS_EU Unit on Speed, inquiry activities are presented for introducing the concept of velocity. Kinematics is a topic found on both lower and upper level science curricula across Europe, and forms the basis for many advanced topics in physics. This unit can be used for development of many inquiry skills, such as planning investigations, developing hypotheses, forming coherent arguments and working collaboratively. In addition, students develop their scientific reasoning and scientific literacy.

The SAILS EU unit reported on assessment opportunities included in this unit which include teacher observation and classroom dialogue, evaluation of student artefacts and self-assessment. The SAILS EU unit was trialed in four countries – Turkey, Ireland, Portugal and Germany – producing four case studies (students aged 12-18yo; mixed ability and gender). The teaching approach was bounded inquiry in all cases. The skill of planning investigations was assessed in all case studies, while skill in forming coherent arguments and working collaboratively were assessed in some case studies, along with scientific reasoning and literacy. Assessment was primarily formative and achieved through classroom dialogue, teacher observation, and evaluation of student artefacts.

Additional Recommendations

The SAILS EU unit was originally developed to consist of eight activities (activities A-H), however, only activities A and B were implemented in the SAILS EU case studies, as these are most suited for beginning any inquiry about speed. The six other inquiry activities (C-H) were included as further investigations to develop student conceptual understanding of velocity and acceleration. They can be used directly after the first two activities or independently in the case of an advanced physics class.

Closing by a teacher (5 min)

This is an opportunity for the teacher to check understanding regarding the science concepts and fair testing. To close the lesson the teacher summarizes and, where relevant, extends the lesson to the next topic/class.

Science behind

The concept in this unit is to support students to collect and record accurate and reliable data, so they can develop their understanding of the relationship between distance, time and speed. This unit is concerned with the physical concepts of speed and velocity and the absolute value of velocity and its distinction from the concept of speed. Students are asked to consider how fast they can go in a certain time and consider factors that affect the accuracy of recording the variables of time and distance, e.g. the floor surface, who is walking, precisely when do they start/stop recording time, where do they measure distance from/to? Several inquiry skills are central in the activities of this unit, including planning investigations, controlling variables, carrying out an investigations and scientific reasoning.

Credits: p. 87 Microsoft Office Stock Images; p.88 Workshop Images from RISE Project, Dublin

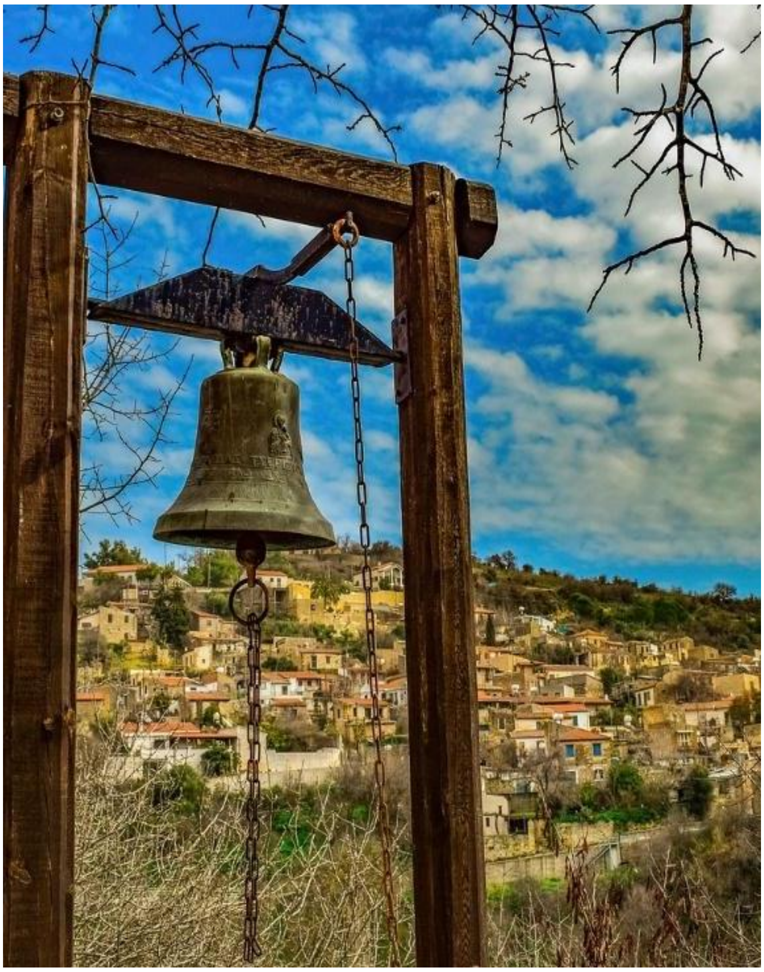
Co-funded by the
Erasmus+ Programme
of the European Union

RISE

Indians, bells & whistling bottles

Teacher Guide

Dagmara Sokołowska



Structured, guided & semi-open inquiry

Introduction

This unit aims to introduce the learners to the concept of sound frequency, sound propagation in matter, and the resonator.

Curriculum topics

It can be used in physics lessons about:

- sound propagation in different states of matter
- simple musical instruments
- standing waves and musical sounds
- experimenting with sounds

During classes, students use low-cost materials, easy to find at home. Measurements are taken using ICT tools, i.e., apps like *Spectroid* and *Phyphox.*

IBL level

The module is embedded into the IBL cycle at the level of guided inquiry. An extension to the open inquiry level is possible. Students experience different aspects of playing and calibrating non-standard instruments: spoons, glass bottles, and wine glasses.

Age of students

The Brainstorming proposed below should start any IBL unit. PART 1 (Bells) of the module can already be used in science classes for 7-12yo students. PART 2 is recommended for courses in lower secondary school. Parts 2 – 4 can be implemented in a high school.

Practicalities

Materials

PART 1.

- kitchen spoons of different lengths from the same cutlery set
- scissors
- cotton yarn or sewing thread
- (optional) school xylophone
- (optional) guitar string

For PARTS 2 – 4.

- water containers, preferably with a volume scale
- paper towel
- smartphones
- rulers

PART 2.

- mineral water glass bottles (cone shape)

PART 3.

- wine glasses

PART 4.

- glass bottles with a more complex shape (e.g., beer bottles)

ICT component (app installation and testing)

For PARTS 2 – 4.

To collect measurements of sound frequency, students are asked to install and test any app on their smartphones, enabling the recording of sound frequency (e.g., *Spectroid* and *Phyphox*). Each student does it individually, but students discuss different apps' effectiveness and accuracy in groups. Finally, only one app installation per group is necessary.

Grouping

Groups of 3-4 students are preferable. Students assign among themselves the roles: secretary (taking notes), musician (playing the instrument), and 1-2 investigators (taking measurements).

Setting

CLASSROOM.

Nest arrangement of students' tables is advised. Tables should be as far apart as possible. Students take notes in the worksheets.

REMOTE.

For the brainstorming – students are in the main room. For conducting experiments – students in breakout rooms, taking notes on the *Jamboard* (each group takes a separate slide).

IBL unit

Brainstorming (10-15 min)

The brainstorming aims to introduce learners to the topic by benefitting from their everyday knowledge and previous knowledge from physics or music classes. All students should be given the floor.

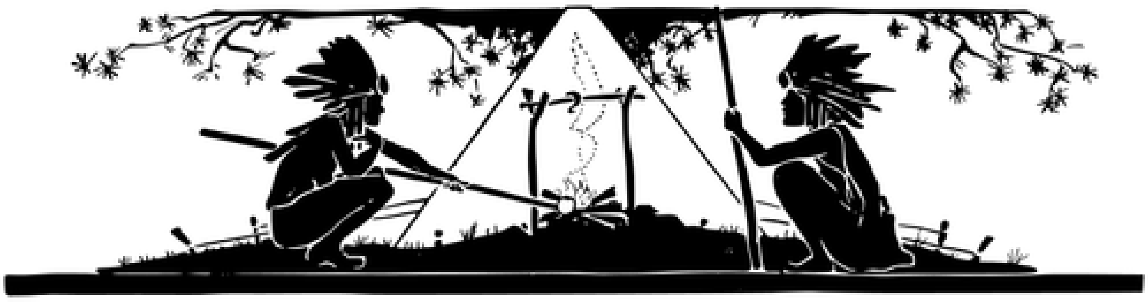
A storyline can be composed around:

How did the Indians (native Americans) use physics, chemistry, and medicine?

or any other story involving learners benefiting from their prior knowledge and experience.

The purpose is to learn that:

- Indians used physics, chemistry, and medicine naturally (exchange of information from different contexts)
- sounds are produced as a mechanical wave in a particular medium
- sounds can propagate in solids, liquids, and gases
- sound dumping is different in different states of matter
- people used different instruments in the history of human beings
- sound is characterized (among others) by its frequency



PART 1. Bells (10 min)

At the end of the brainstorming, **a short experiment/observation** is proposed by listening to the sounds produced by a spoon in the air and through the solid state (thread). If the module is continued to PART 2, PART 1 can be included in the brainstorming as its extension.

1. Each group of students is given one tablespoon, a piece of cotton yarn, or another similar thread (approx. 80 cm long)
2. Students are asked to prove that the sound propagates better (i.e., less damped) in a solid than gas (air).
3. One possible solution (very appealing to students) is to tie a spoon in the middle of the thread with two loose ends. A specific sound is produced when a student swings the spoon on two parts of the thread and hits the table. However, when they do the same with two ends of the thread pressed against the earlobes, it is hearable that the sound is “richer” (composed of many sounds), and it resembles the bells in the temple.
4. Students are asked to investigate phenomenologically how the primary frequency of the sound produced, as described in (3), depends on the length of a spoon from the same cutlery set. After the conclusion, the xylophone can be recalled (or shown), as well as the way the guitar string is played to get a higher or lower sound.

PART 2. Whistling bottles 1 (25 min)

This part of the IBL unit aims to investigate the relationship between the frequency of the sound and the length of the air column (or the wavelength).

1. Each student is given an empty cone-shaped glass bottle.
2. Teacher asks students to play a sound with the use of an empty bottle. Students compare the sounds of different bottles (frequency, volume), if available.
3. Teacher poses a question:
   How does the sound frequency depend on the air column's height over the water surface?

   or

   The teacher asks (older, more advanced) students:

   What parameter related to the bottle can be assigned as an independent parameter determining the primary frequency of the sound produced by blowing over the neck of the bottle?

4. Students in groups:
   - formulate an inquiry question if the teacher does not pose it
   - discuss and put forward a hypothesis
   - plan the investigation in which they change the amount of water in the bottle and investigate the frequency of the sound produced each time
   - collect materials
   - conduct the experiment
   - collect and visualize data on the graph
   - draw conclusions
   - present their group findings to the class (last 5 min)
5. Students can fit the data or speculate about the type of function that could fit the data (depending on students' level). Students or a teacher can conclude about the sound frequency dependence on the length of the air column in the bottle. Looking closer, students can detect that, in fact, there are two regions in the graph where data can be fitted with two different functions.
6. At the end teacher should advert to PART 1 results in PARTS 1-2 should be compared.

PART 3. Musical wine glasses (45 min)

This part of the IBL unit aims to investigate the relationship between the frequency of the sound and the length of the water column (or the wavelength). Comparison with PARTS 1-2 should help students to reflect on the general rules of the frequency dependence on a longitudinal dimension of the resonator. Students should come to the conclusion of how the sound is amplified in each case.

1. Each group is given an empty wine glass.
2. Teacher asks students to play a sound on an empty glass border. Students discuss how to do that.
3. Teacher poses a task:
   Investigate the dependence of the sound frequency on a selected parameter (independent variable).

4. Students in groups:

- select an independent variable
- formulate an inquiry question
- discuss and put forward a hypothesis
- plan the investigation in which they change the amount of water in the glass and investigate the frequency of the sound produced each time
- collect materials
- conduct the experiment
- collect and visualize data on the graph
- draw conclusions
- present their group findings to the class (last 5-10 min)

5. Students can fit the data or speculate about the type of function that could fit the data (depending on students' level).
6. At the end teacher should refer to the results in PART 1 & 2, and students should compare them with the outcomes in PART 3. A short discussion should be conducted about the explanation of occurring differences. In particular, students should reflect on how the sound is produced in each part.

PART 4. Extension – whistling bottles 2 (45 min)

This part of the IBL unit aims to investigate the relationship between the frequency of the sound and the length of the air column (or the wavelength). Since the shape of the resonator is complex, students develop their data analysis skills and interpretation of data.

Students can also come to a different idea about the inquiry question and the investigation, not following what was already investigated in PARTS 1-3.

1. Each group is given an empty beer bottle (or any bottle in a two-cylinder shape).
2. Teacher poses a task:
   Investigate the sounds with the use of this bottle.

3. Students in groups:
- select an independent variable
- formulate an inquiry question
- discuss and put forward a hypothesis
- plan the investigation
- collect materials
- conduct the experiment
- collect and visualize data on the graph
- draw conclusions
- present their group findings to the class (last 5-10 min)

4. Students can fit the data or speculate about the type of function that could fit the data (depending on students' level).
5. At the end teacher should refer to the results in PART 1, 2 & 3, and students should compare them with the outcomes in PART 4. A short discussion should be conducted about the explanation of occurring differences and their possible reasons.

Closing by a teacher (5 min)

The teacher summarizes and extends the lesson to the next topic/class.

Physics behind

Musical sounds can be set up by oscillating pieces of solids (strings, membranes), liquids and gases (air columns). When the sound propagates in gas or liquid in any resonant cave or along a solid (bars, strings), the standing waves can be set up. If the wavelength of the waves matches the length of the metal bar, string, air column in a pipe, etc., the superposition of waves traveling in opposite directions creates a standing wave pattern. The wavelength required of the waves for such a match is one that corresponds to the resonant frequency of the instrument. There are different rules for standing wave wavelengths, depending on the type of instrument. In handbooks, only the basic examples of producing musical sound are elaborated by derivation of the relationship between the length of the instrument and the wavelengths of the prime and other harmonics. Usually, the content is limited to pipes (with open and closed ends) and strings, with repetitive inverse proportion between the frequency of the sound and the sound wavelength (and thus also the length of the instrument). In this IBL unit such a relationship is reproduced to a good approximation in PART 2. In more complicated cases, such as a wine glass or a beer bottle, more complex relations are observed.

Credits: p. 97 dimitrisvetsikas1969 (Pixabay); p.98 Bells in Poland, public domain; p. 100 Public Domain (publicdomainvectors.org); p. 101 Cone bottles of mineral water, own work (D. Sokołowska); p. 102 Musical glasses, Baltimore (United States), about 1830, Exposition in the National Museum of Arts, Boston, USA own work (D. Sokołowska); p.103 High-school implementation of the unit, own work (D. Sokołowska)

Co-funded by the
Erasmus+ Programme
of the European Union

Cooking Spaghetti

Teacher Guide

Eilish McLoughlin
James Lovatt
Paul Grimes

Open inquiry

Introduction

Students are asked to plan and carry out an investigation to cook the perfect spaghetti. Students are asked to consider what factors will affect the cooking of the spaghetti and what variables they should measure and record. Students must also discuss and agree how they will determine when they have cooked the perfect spaghetti.

Curriculum topics

It can be used in science lessons about:

- relationship between mass, volume and density
- states of matter,
- temperature change,
- physical and chemical changes
- measurement and proficient use of measurement devices
- planning investigations
- controlling variables
- recording and analyzing scientific data

Students use everyday materials to complete this experiment. Most of the materials can be found in the home so students can easily do this in the school lab or remotely.

IBL level

The unit is strongly linked to planning and carrying out investigations during the IBL cycle. An open inquiry approach is adopted and students are required to collaborate to make decisions during all stages of the inquiry process.

Age of students

This unit is designed for lower secondary level (12-14 yo students). The unit can be used as an introduction to scientific measurement and/or could be used to introduce students to the inquiry skills of planning and carrying out investigations.

Practicalities

Materials

- Packet of (uncooked) spaghetti;
- Saucepan and lid
- Water
- Salt
- Sugar
- Cooking Oil
- Vernier calipers
- Ruler / metre stick
- Kitchen / Weighing Scales
- Thermometer / temperature probe
- Hob or Hot-plate

ICT component (app installation and testing)

There is no specific ICT element for this unit. It is useful to use Google documents to collect student responses to a shared worksheet and either a physical/online placemat to share findings and conclusions between groups.

Grouping

Small group work (2-3 students) is preferable in this unit. All students should engage in all activities.

Setting

CLASSROOM.

Students should have space to safely set up the experiment and that all groups have access to a hotplate/hob.

REMOTE.

For the main discussions students should be in the main room. For conducting investigations, students should be facilitated in their small groups to collaborate in breakout rooms. Students need to use an online collaborative tool, such as google documents, to share their responses with their own group members and during whole class discussions.

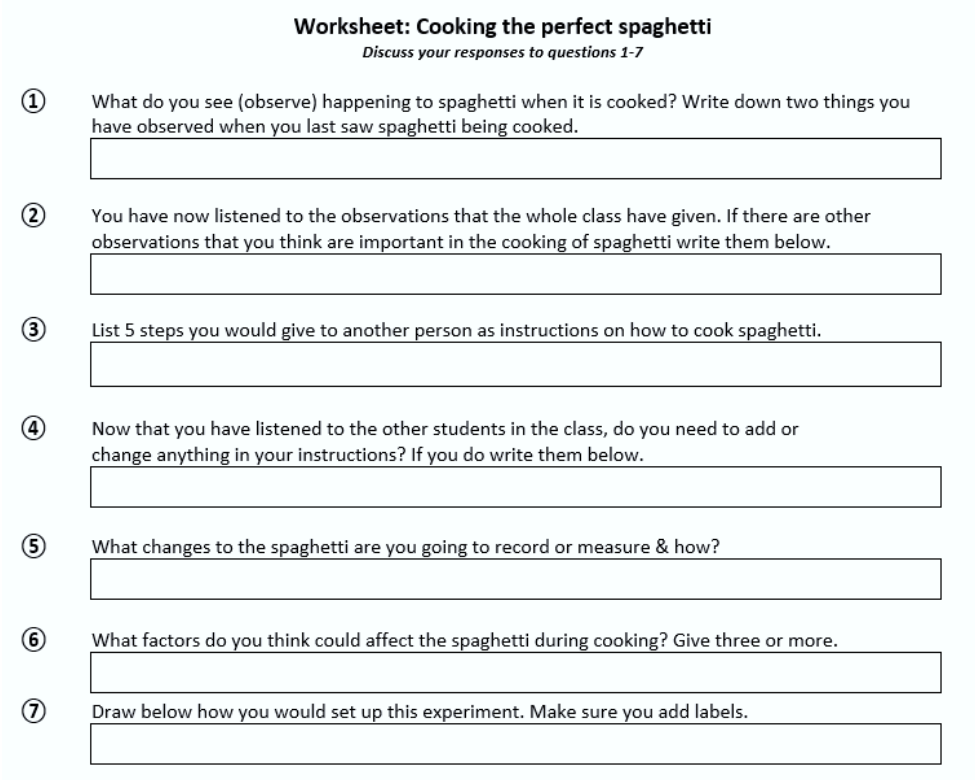
IBL unit

PART 1: INTRODUCTION (20 min)

Students are facilitated to collaborate in small groups to plan an investigation for the inquiry question: How to cook the perfect spaghetti? In planning their investigation, students are prompted to consider the following questions:

- What you see (observe) happening to spaghetti when it is cooked?
- What is your method for cooking the perfect spaghetti?
- What changes to the spaghetti are you going to record or measure & how?
- What factors do you think could affect the spaghetti during cooking?

Students are asked to draw on their experiences (or observations) of what happens when you cook spaghetti and fill in their responses to 7 questions on shared worksheet.



Worksheet: Cooking the perfect spaghetti

Discuss your responses to questions 1-7

① What do you see (observe) happening to spaghetti when it is cooked? Write down two things you have observed when you last saw spaghetti being cooked.

② You have now listened to the observations that the whole class have given. If there are other observations that you think are important in the cooking of spaghetti write them below.

③ List 5 steps you would give to another person as instructions on how to cook spaghetti.

④ Now that you have listened to the other students in the class, do you need to add or change anything in your instructions? If you do write them below.

⑤ What changes to the spaghetti are you going to record or measure & how?

⑥ What factors do you think could affect the spaghetti during cooking? Give three or more.

⑦ Draw below how you would set up this experiment. Make sure you add labels.

PART 2. Identifying/Controlling variables (15 min)

Students are provided with a packet of uncooked spaghetti and a selection of measurement devices and prompted to identify and consider what variables they can measure and record. Following discussions among group members, the teacher facilitates a whole group discussion to identify variables that could be measured/controlled during their investigation. This includes:

- total mass of spaghetti
- mean mass of a spaghetti strand
- mean length of spaghetti strands used
- mean diameter of a spaghetti strand
- type of spaghetti
- broken/whole spaghetti strands
- volume of water used
- temperature of the water
- time allowed for cooking

Students also discuss factors that affect their investigation and accuracy of measurements, such as:

- addition of salt/oil
- lid/no lid on cooking vessel
- cooking vessel: lab glassware or kitchenware
- dimensions of the cooking vessel – base diameter/thickness
- difficulty in measuring spaghetti accurately after cooking

PART 3. Carrying out an investigation (30 min)

Students are encouraged to debate and write a clear definition of what is the "perfect spaghetti", e.g. the perfect spaghetti should be slightly al dente, not soft or gummy, it will be sticky enough to hold sauce, but not so sticky that it sticks to itself.

Students share and discuss their plans with each other and identify several variables that will change during the cooking process, such as: the mass, length, diameter, volume, density of a single spaghetti strand. They discuss the effect of the type of spaghetti used, volume and temperature of the water used, addition of salt or oil, lid/no lid on cooking vessel and time allowed for cooking.

Students collaborate in small groups to write an agreed plan for how they will carry out their investigation. Groups should use a shared worksheet so that all members discuss/agree on all steps of their plan and explicitly state how they will record their results.

The description of the endpoint of the experiment is something that each group has to agree upon before starting the practical investigation and list it as one of the points of their plan. Students may follow the practice in their home e.g. 8 minutes boiling, the instructions on the packet of spaghetti, al dente, or some may suggest throwing it at the wall to see if it sticks!

Students carry out their investigation according to their agreed plan and compare their findings with other student groups. They are facilitated to reflect on their plans and if/how they have controlled and measured variables.

PART 4. Reflecting on learning (15 min)

In this part of the IBL unit students reflect on what knowledge/skills they have developed while carrying out this activity. Teachers can facilitate this reflection in a variety of ways, individual reflection, think-pair-share or as a whole discussion. Teachers can adapt this IBL to focus on particular learning outcomes. In general, after completing this unit students should be able to:

- Identify the appropriate instrument to measure temperature, mass, length and diameter.
- Identify one method for measuring temperature, mass, length and diameter.
- Perform simple tasks to measure temperature, mass, length and diameter.
- Offer a variety of solutions for their predictions.
- Identify the most appropriate solution for a given measurement problem in relation to temperature, mass, length and diameter.
- Explain all the key terms, and units.
- Offer scientific explanations for what they observe in their experiments.
- Calculate mean temperature, mass, length and diameter.
- Offer plausible alternatives for each of the measurements.
- Discuss probable sources of error and discuss how these may be overcome.
- Relate these measurement skills to other areas.
- Consider further refinements for their investigation.
- Use formulas to calculate absolute and percentage errors.

PART 5. Extension Activities – (45 min)

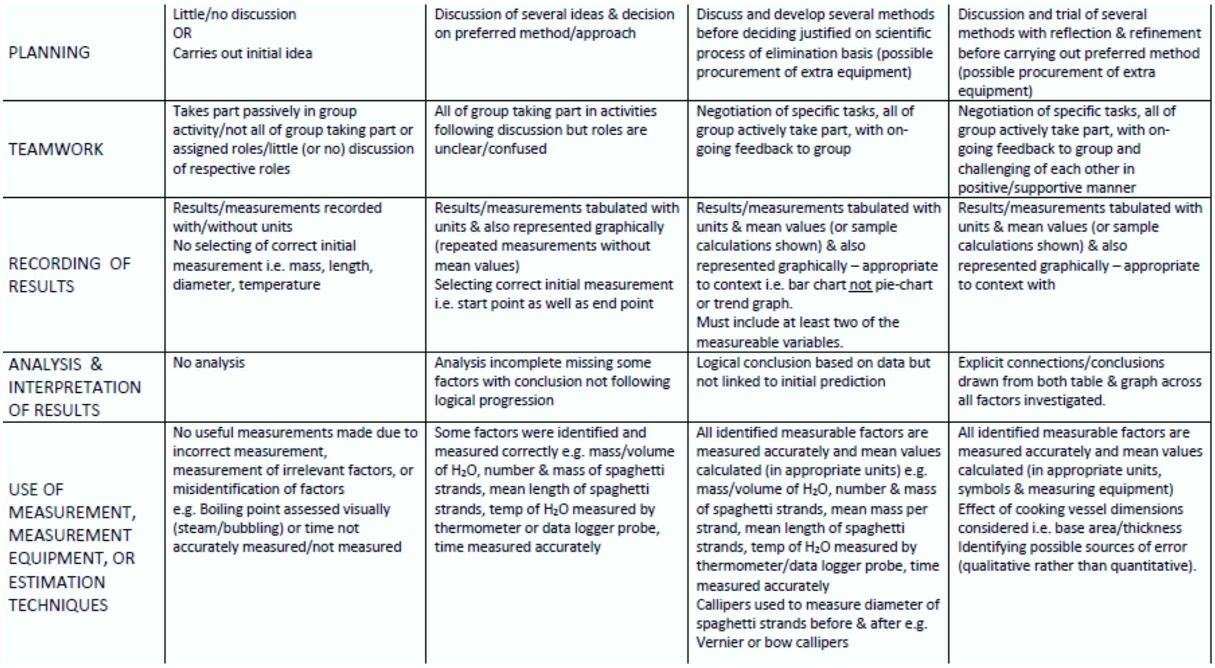
In this unit the focus was on developing students skills to plan a scientific inquiry based on the everyday activity of cooking spaghetti. Students were prompted to brainstorm and identify variables that they could measure and control during this investigation. An open inquiry approach is used in this unit and students are responsible for deciding what variables they will control/measure, what data they will collect, how they will record/analyze their data, what criteria they will use to compare their results.

These activities are adopted from the SAILS EU Unit on Cooking Food. It can be found online in Sharing Practices section of the EU SAILS project: http://sails-project.eu/files/sharing-practices/86/document.pdf

The SAILS EU Unit on Cooking Food was designed for 12-13 yo students in Ireland. Its main purpose is to encourage students to consider the science behind an everyday experience that they may be familiar with and to recast that experience in a scientific setting. By doing this it is hoped that students will begin to exercise and develop skills specifically in the following four skill areas:

- Measurement and proficient use of measurement devices;
- Recording and analysis of results/observations in formats appropriate to the context;
- Planning skills;
- Teamwork.

An assessment rubric for each of these four skills is also provided (as below). The student sheet and groupwork sheet used in this unit are intended to elicit written responses under the four intended skill categories, but could be enhanced by requiring students to produce a formal report under specified headings and collating this with the two worksheets. This is in addition to any assessment that could be carried out by the circulating teacher during the assessment – making notes about individuals/groups that could be added into written/verbal feedback to students.



PLANNING	Little/no discussion OR Carries out initial idea	Discussion of several ideas & decision on preferred method/approach	Discuss and develop several methods before deciding justified on scientific process of elimination basis (possible procurement of extra equipment)	Discussion and trial of several methods with reflection & refinement before carrying out preferred method (possible procurement of extra equipment)
TEAMWORK	Takes part passively in group activity/not all of group taking part or assigned roles/little (or no) discussion of respective roles	All of group taking part in activities following discussion but roles are unclear/confused	Negotiation of specific tasks, all of group actively take part, with on-going feedback to group	Negotiation of specific tasks, all of group actively take part, with on-going feedback to group and challenging of each other in positive/supportive manner
RECORDING OF RESULTS	Results/measurements recorded with/without units No selecting of correct initial measurement i.e. mass, length, diameter, temperature	Results/measurements tabulated with units & also represented graphically (repeated measurements without mean values) Selecting correct initial measurement i.e. start point as well as end point	Results/measurements tabulated with units & mean values (or sample calculations shown) & also represented graphically – appropriate to context i.e. bar chart not pie-chart or trend graph. Must include at least two of the measureable variables.	Results/measurements tabulated with units & mean values (or sample calculations shown) & also represented graphically – appropriate to context with
ANALYSIS & INTERPRETATION OF RESULTS	No analysis	Analysis incomplete missing some factors with conclusion not following logical progression	Logical conclusion based on data but not linked to initial prediction	Explicit connections/conclusions drawn from both table & graph across all factors investigated.
USE OF MEASUREMENT, MEASUREMENT EQUIPMENT, OR ESTIMATION TECHNIQUES	No useful measurements made due to incorrect measurement, measurement of irrelevant factors, or misidentification of factors e.g. Boiling point assessed visually (steam/bubbling) or time not accurately measured/not measured	Some factors were identified and measured correctly e.g. mass/volume of H_2O, number & mass of spaghetti strands, mean length of spaghetti strands, temp of H_2O measured by thermometer or data logger probe, time measured accurately	All identified measurable factors are measured accurately and mean values calculated (in appropriate units) e.g. mass/volume of H_2O, number & mass of spaghetti strands, mean mass per strand, mean length of spaghetti strands, temp of H_2O measured by thermometer/data logger probe, time measured accurately Callipers used to measure diameter of spaghetti strands before & after e.g. Vernier or bow callipers	All identified measurable factors are measured accurately and mean values calculated (in appropriate units, symbols & measuring equipment) Effect of cooking vessel dimensions considered i.e. base area/thickness Identifying possible sources of error (qualitative rather than quantitative).

Extract from SAILS EU Unit on cooking food

Closing by a teacher (5 min)

This is an opportunity for the teacher to check student's understanding of relevant science concepts and development of inquiry skills, such as developing hypotheses, controlling variables, fair testing, planning and carrying out scientific investigations. Teachers and students are encouraged to reflect on some of the ideas they have about fair testing in planning and carrying out investigations to ensure their plan presents an appropriate method to measure data that is repeatable, reliable and reproducible. To close the lesson the teacher summarizes and where relevant extends the lesson to the next topic/class.

Science behind

The concept in this unit is about cooking the perfect spaghetti. However, not everyone has the same opinion about what is the perfect spaghetti. E.g. The perfect pasta should be slightly al dente, not soft or gummy. It will be sticky enough to hold sauce, but not so sticky that it sticks to itself.

There are three key components to cooking spaghetti:

- The sticky starch (amylopectin) is a highly branched, soluble polysaccharide. If your cooked spaghetti sticks together, ending up looking like a ball of yarn, amylopectin is the starch doing the sticking.
- The not so sticky starch (amylose) is a starch molecule that becomes gelatinized at temperatures above 65 degrees Celsius. It's tightly packed, not as branched a molecule, compared to amylopectin. It is insoluble in water and acts as an emulsifier, blocking tiny fat molecules, helping even the oiliest of sauces bind to the pasta.
- The protein in the spaghetti mainly comes from egg, a little from the flour, but protein is an important part in pasta making. As the spaghetti cooks, it forms a sort of string bag that holds the starch granules in place.

Further details on the chemistry of cooking the perfect pasta is available on:

- https://www.materials-talks.com/the-chemistry-of-cooking-the-perfect-pasta-amylopectin-amylose-and-protein/

Several research articles have been published on models for the cooking-induced deformation of spaghetti, e.g.

- Nathaniel N. Goldberg and Oliver M. O'Reilly, Mechanics-based model for the cooking-induced deformation of spaghetti," *Phys. Rev. E* 101, 013001 (2020). https://doi.org/10.1103/PhysRevE.101.013001
- Jonghyun Hwang, Jonghyun Ha, Ryan Siu, Yun Seong Kim, Sameh Tawfick; Swelling, softening, and elastocapillary adhesion of cooked pasta. *Physics of Fluids* 1 April 2022; 34 (4): 042105. https://doi.org/10.1063/5.0083696

Credits: All the images used have been taken during Workshops with teachers as part of the RISE Project, Dublin, own work

Co-funded by the
Erasmus+ Programme
of the European Union

Ice balloons

Teacher Guide

Eilish McLoughlin

James Lovatt

Paul Grimes

Raising inquiry questions

Introduction

This inquiry unit aims to develop the skill of raising questions around interesting phenomena. In this case, we use ice balloons - water-filled balloons that have been frozen and then peeled to reveal a ball of ice. The focus of this unit is to develop student's awareness of the role of inquiry questions in the investigation process and facilitate them to distinguish between questions that are investigable or non-investigable. Students develop criteria for investigable questions and collaborate to turn non-investigable questions into investigable ones.

Curriculum topics

It can be used in science lessons about:

- density,
- states of matter,
- temperature change,
- formations and structures in the ice.
- developing inquiry questions
- planning investigations

Students use basic materials to complete this experiment. Most of the materials can be found in the home, so students can easily do this in the school lab or remotely.

IBL level

The unit is strongly linked to the first stage of the IBL cycle and supports students in developing skills in brainstorming and raising questions around phenomena.

Age of students

This unit is designed for lower secondary level (12-14 yo students). The unit can be used as an introduction to the concept of density and/or could be used to introduce students to the inquiry cycle.

Practicalities

Materials

- prepare two ice balloons in advance
  - Fill one balloon with 1 pint of tap water and fill one balloon with 1 pint of sparkling water.
  - Place in a freezer for at least 24-48 hours.
- food colouring (e.g. red/blue/green)
- Salt
- Sugar
- washing up liquid
- magnifying glass
- tub or bowl that the balloon can fit into
- tray/dish/plate to sit the balloon on
- toothpicks
- hammer/mallet
- nails
- torch
- sticky notes/online collaborative tool to share responses

ICT component

CLASSROOM.

There is no specific ICT element for this unit

REMOTE.

It is useful to use *Google Jamboard* to collect student responses.

Grouping

Small group work (2-3 students) is preferable in this unit. All students should engage in all activities.

Setting

CLASSROOM.

Students should have space to set up the experiment and access to tap water. Students should be given sticky notes to record their responses.

REMOTE.

For the main discussions students should be in the main room. For conducting investigations, students should be facilitated in their small groups to collaborate in breakout rooms. Students need to use an online collaborative tool, such as *Jamboard*, to share their responses with their own group members and during whole class discussions.

IBL unit

Part A: INTRODUCTION (20 mins)

Students are asked to observe and carry out some simple experiments to examine the features and properties of ice balloons - one made with fresh water and one made with sparkling water. Students work in small groups to brainstorm ideas and record as many questions as possible based on their own observations and experiments. A range of questions/prompts can be used by the teacher to encourage students to use different materials and observe the effect they have on the ice balloon. The use of Google Jamboard allows all group members to add sticky notes simultaneously and strongly encourages collaboration and sharing of ideas.

Part A: What questions do you have?

Link to Jamboard (Groups 1-12)

- Peel the balloon off the ice.
- Begin by noticing everything you can about the balloon, simply by looking.
- Use a flashlight to illuminate the ice.
- Use a magnifying glass to see more details.
- What do you notice about the ice? Do you notice “spikes,” cracks, or frost?
- Use a paper clip/toothpick to explore the surface of the ice.
- What do you notice about how wood and metal objects interact with the ice?
- What happens when you pore salt on the ice?
- What happens when you put some drops of food coloring on the ice?
- What happens when you place your ice balloon in a tub of water?

Part A: What questions do you have?

Group

Why is one ballon collapsed?

Do Sparkling Water and still water expand at the same rate?

Does one sound different when you knock on or hit it?

Why does one balloon appear larger than the other?

Did you put the same amount of water in both?

Would Coke be more caved in than the sparkling water?

Are there bubbles in the sparkling water one?

What makes water cloudy?

Was the balloon more stuck to one than the other?

Why do the sparkling water ones have a crater?

Why is the fizzy one easier to cut?

Is one going to defrost faster than the other?

Are they the gas bubbles escaping?

Is one cloudier than the other?

What's the frosty part in the middle?

If you lick them, is there a difference in the taste?! :P

Are the surfaces of both the same? Is one shiny?

Why is the outside clear and the inside cloudy?

Are glaciers clear or cloudy? Do they have gas?

Is the light able to travel further through sparkling water because of gas bubbles?

Why is one more transparent than the other?

Is the hole to do with the bubbles or just because he didn't fill the balloon properly?

Is one easier to break than the other?

Why would they melt at different rates?

Why is it becoming more transparent?

Are they melting at the same rate?

What happens when you put 50:50 Salt: Sugar on both ice blocks?

Where did the lines come from?

If you drop them from a meter height, do bits come off in the same way?

How can we make clear ice?

What would make the sparkling melt faster? The gas bubbles?

What are the spikes?

Why does it melt more with salt?

PART 2. Sorting Questions (15 min)

Students are asked to select one question from their list of questions and consider how they might go about investigating it. The teacher prompts the students to consider that investigating often involves cycles of questioning: raising questions, experimenting, and asking new questions based on new observations. Students are asked to sort their questions into two lists: investigable and non-investigable questions.

- Sort your questions into two piles.

*questions you think are **"investigable"***	*questions you think are **"non-investigable"***

- Select one question and consider how you might go about investigating it.

Investigating often involves cycles of questioning: observing, raising questions, experimenting, and asking new questions based on new observations.

Why is one ballon collapsed?
Would Coke be more caved in than the sparkling water?
Do Sparkling Water and still water expand at the same rate?
If you lick them, is there a difference in the taste?! :P
Is one easier to break than the other?
Why do the sparkling water ones have a crater?
Are they melting at the same rate?
Was the balloon more stuck to one than the other?
Is one going to defrost faster than the other?
Is one cloudier than the other?
What's the frosty part in the middle?
Does one sound different when you knock on or hit it?
What happens when you put 50:50 Salt: Sugar on both ice blocks?
Is the light able to travel further through sparkling water because of gas bubbles?
Is the hole to do with the bubbles or just because he didn't fill the balloon properly?
Did you put the same amount of water in both?
If you drop them from a meter height, do bits come off in the same way?
Are they the gas bubbles escaping?
How can we make clear ice?
What would make the sparkling melt faster? The gas bubbles?

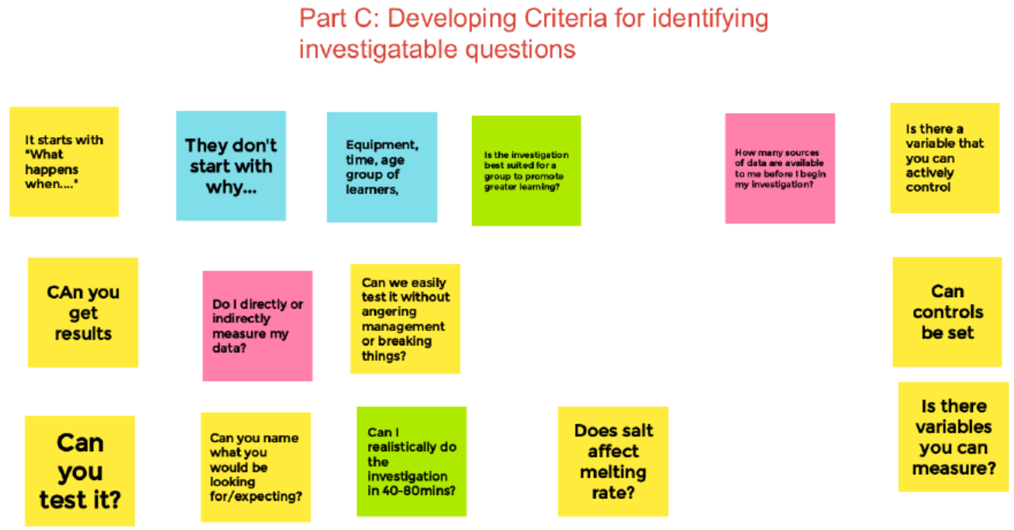
Why is the fizzy one easier to cut?
What are the spikes?
Are there bubbles in the sparkling water one?
What makes water cloudy?
Why does one balloon appear larger than the other?
Why is it becoming more transparent?
Why is the outside clear and the inside cloudy?
Where did the lines come from?
Why does it melt more with salt?
Are glaciers clear or cloudy? Do they have gas?
Are the surfaces of both the same? Is one shiny?
Why would they melt at different rates?
Why is one more transparent than the other?

PART 3. Developing Criteria for inquiry questions (10 min)

In this part of the IBL unit students work in small groups to identify and discuss what is the criteria for an investigable question. The teacher facilitates a whole group discussion to record a list of criteria with input from all students/groups.

- Examine your investigable and non-investigable questions
- Think about what makes a question investigable
- Come up with criteria for identifying investigable questions.
- Record your criteria on Jamboard

The teacher prompts students to consider factors that determine if a question is investigable or non-investigable. Students consider what materials are available, what variables can be controlled, what time is needed to carry out the investigation, can they measure data and get results. Different Kinds of Questions



Part C: Developing Criteria for identifying investigatable questions

It starts with "What happens when...."

They don't start with why...

Equipment, time, age group of learners,

Is the investigation best suited for a group to promote greater learning?

How many sources of data are available to me before I begin my investigation?

Is there a variable that you can actively control

CAn you get results

Do I directly or indirectly measure my data?

Can we easily test it without angering management or breaking things?

Can controls be set

Can you test it?

Can you name what you would be looking for/expecting?

Can I realistically do the investigation in 40-80mins?

Does salt affect melting rate?

Is there variables you can measure?

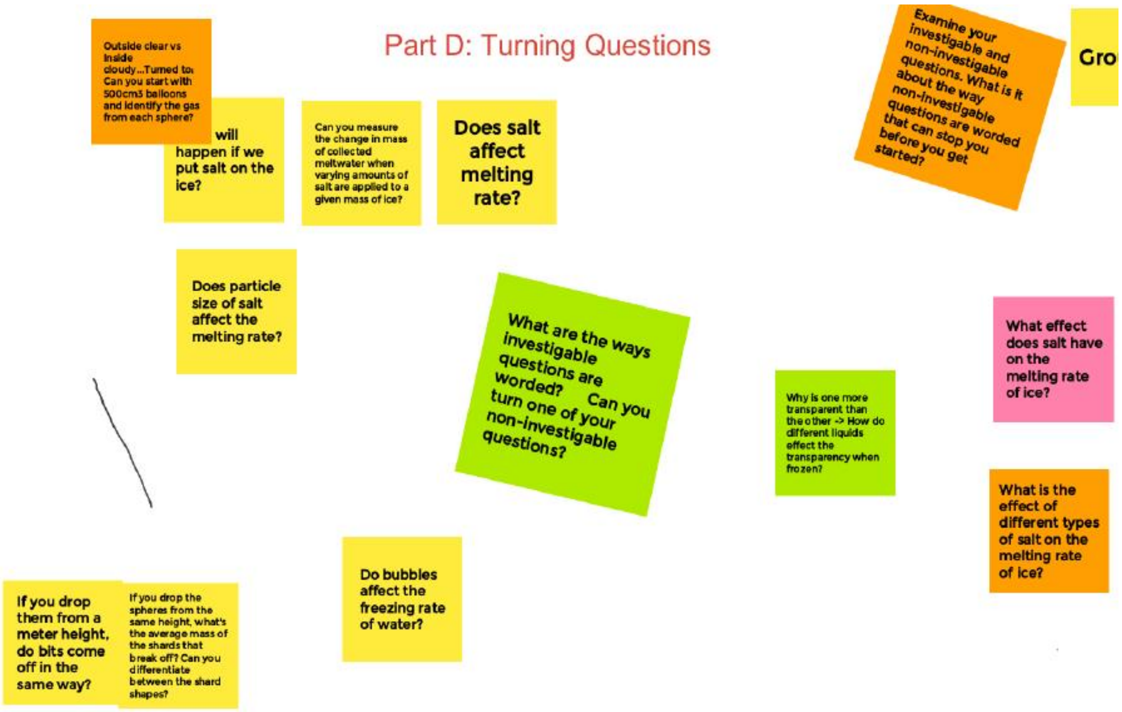
Questions that lead to taking action are considered "investigable." For example, questions that begin with what will happen if . . . or contain the phrase does the ______ make a difference can be investigated. The way they are phrased invites one to experiment with materials and phenomena. "What will happen if we put salt on the ice?" or "Does the temperature of the water make a difference?" indicate a clear course of action. Conversely, questions that do not lead to taking hands-on action are considered "non investigable." For example, questions that begin with why—such as "Why is most of the ice balloon underneath the water?" or "Why are parts of the ice balloon cloudy?" are considered non investigable. They're stated in a way that does not lead directly to hands-on action that would help answer the question as stated. Instead, they're requests for information or explanations. Answering these kinds of questions will probably require obtaining information from a book, the Internet, or a person who has experience in the area. While investigations can be conducted using such resources, this workshop addresses investigations that take place through firsthand experiences with materials and phenomena. (For further details see https://www.exploratorium.edu/sites/default/files/pdfs/ifi/Raising_Questions.pdf page 34)

PART 4. Turning Questions (15 min)

The students are asked to review their list of investigable questions and consider how these questions are worded. Students are asked to take one of the non-investigable questions and rephrase it to turn into an investigable question.

Part D: Turning Questions

- Examine your investigable and non-investigable questions
- What is it about the way non-investigable questions are worded that can stop you before you get started?
- What are the ways investigable questions are worded?
- Can you turn one of your non-investigable questions?



Part D: Turning Questions

Outside clear vs Inside cloudy...Turned to: Can you start with 500cm3 balloons and identify the gas from each sphere?

will happen if we put salt on the ice?

Can you measure the change in mass of collected meltwater when varying amounts of salt are applied to a given mass of ice?

Does salt affect melting rate?

Examine your investigable and non-investigable questions. What is it about the way non-investigable questions are worded that can stop you before you get started?

Gro

Does particle size of salt affect the melting rate?

What are the ways investigable questions are worded? Can you turn one of your non-investigable questions?

Why is one more transparent than the other -> How do different liquids effect the transparency when frozen?

What effect does salt have on the melting rate of ice?

What is the effect of different types of salt on the melting rate of ice?

Do bubbles affect the freezing rate of water?

If you drop them from a meter height, do bits come off in the same way?

If you drop the spheres from the same height, what's the average mass of the shards that break off? Can you differentiate between the shard shapes?

PART 5. Extension Activities – (45 min)

In this unit the focus was on brainstorming and raising questions on an interesting phenomena. The focus of this unit is to develop student's awareness of the role of inquiry questions in the investigation process and facilitate them to distinguish between questions that are investigable or non-investigable. Students develop criteria for investigable questions and collaborate to turn non-investigable questions into investigable ones.

This activity is adopted from the Exploratorium Fundamentals of Inquiry Facilitator's Guide Workshop III: Raising Questions, which is available at: https://www.exploratorium.edu/sites/default/files/pdfs/ifi/Raising_Questions.pdf

Raising Questions introduces teachers to ways to stimulate that curiosity, elicit student questions, and move them in productive directions that can ultimately lead to investigations. The Raising Questions workshop provides teachers with new pedagogical understandings and skills rather than activities they can take back to the classroom.

Raising Questions is the third of five workshops in the FUNDAMENTALS OF INQUIRY curriculum, designed to introduce teachers to the benefits of inquiry-based teaching. Though most of the workshops can be used individually, the series is best presented as a comprehensive whole. Below are brief descriptions of the five workshops.

- Workshop I: Comparing Approaches to Hands-On Science Participants discover that different approaches to hands-on teaching support different goals for learning (about 3.5 hours).
- Workshop II: Process Skills Participants identify the tools needed to carry out inquiry—the process skills—and examine the role of these skills in learning (about 3.5 hours).
- Workshop III: Raising Questions Participants examine the kinds of questions learners ask about phenomena and find out how to turn "noninvestigable" questions into "investigable" ones (about 3.5 hours).
- Workshop IV: Stream Table Inquiry Participants experience inquiry firsthand, learning scientific process and content through an extended investigation (about 6 hours).
- Workshop V: Subtle Shifts: Adapting Activities for Inquiry Participants examine how current classroom activities can be modified to incorporate elements of inquiry (about 3 hours).

Closing by a teacher (5 min)

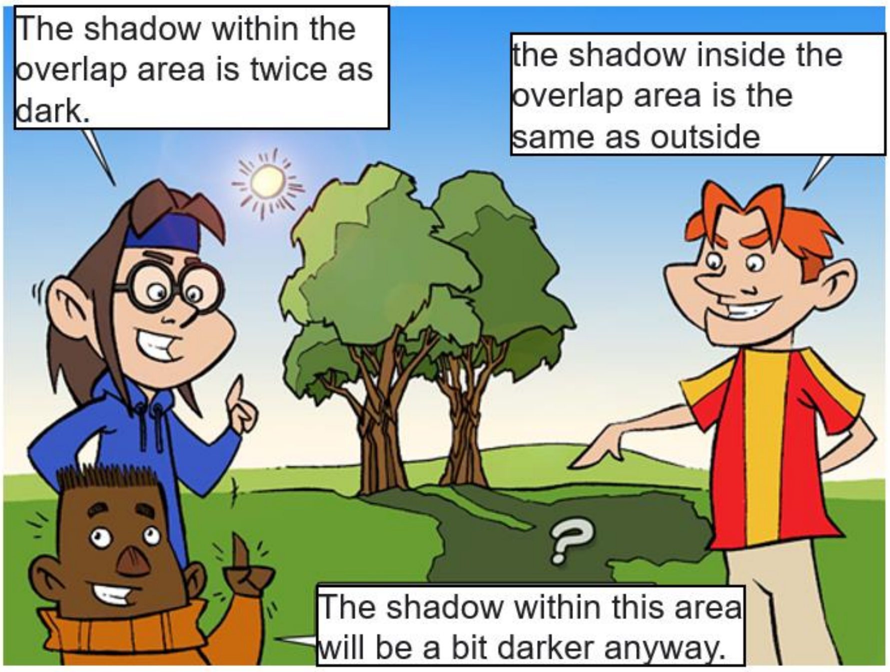
This is an opportunity for the teacher to check student's understanding of relevant science concepts and development of inquiry skills, such as raising questions, developing hypotheses and planning investigations. Teachers and students are encouraged to reflect on some of the ideas they have about questioning, and consider strategies that develop questioning and skills. To close the lesson the teacher summarizes and where relevant extends the lesson to the next topic/class.

Science behind

The concept in this unit is quite basic in that it looks at the factors how water freezes and how ice forms. The use of different types of water prompts students to think about why parts of the ice are clear and parts are cloudy. The water freezes from the outside in. As the ice balloon begins to freeze, air and impurities (naturally present in water) are pushed toward the center, which is still liquid. Eventually, the water freezes around small bubbles of air and these bubbles scatter light so that part appears white. Where there are no bubbles the ice appears clear with a transparent crystalline structure. Students also observe long spikes/columns in the ice balloons. These are created when large bubbles form around a particle in the water, or when small bubbles merge, as the freezing process pushes the bubbles toward the center of the sphere.

Credits: All the images used have been taken during Workshops with teachers as part of the RISE Project, Dublin, own work

Concept Cartoons



Teacher Guide

Reinout Putman
Jan de Lange

All levels of inquiry

Introduction

In this example, a daily life situation is depicted in a cartoon. The four characters present have their individual perspectives on whether shadows exist at night.

You can try the test yourself or share it with someone near you. Which solution do you believe is right? This cartoon already provoked meaningful debates in certain classes.

It is interesting to note that all the views presented are plausible or, at the very least, familiar. All individuals express their views based on personal conceptions of shadows and the night.

Concept cartoons are developed from students' own conceptions, which correspond to known 'alternative conceptions' or Apprentice conceptions.

Pupils think images should not merely be viewed as common errors, but instead require a specific didactic approach. Concept cartoons represent a viable solution to this.

In summary, we can say that concept cartoons:

- invite pupils to think, formulate arguments and lower the threshold for discussion,
- contain very recognizable 'scientific' ideas from everyday situations that are all equally valid, but clash due to different starting points,
- often have no single correct answer,
- can be the starting point for further research.

Curriculum topics

Concept cartoons can be used in all science or technology lessons. It’s a starting point for experiments or to start a talk in your classroom.

IBL level

Concept cartoons can be used as a starting point for all types of IBL levels. As a teacher, you can show your pupils a concept cartoon, let them have a discussion on the topic and start to investigate the matter or you can guide them more and do the experiment yourself in front of the class.

Age of students

Concept cartoons can be used in lower and higher education. We will give some examples on how you can use concept cartoons in a physics lesson about light.

As a teacher you can always make a concept cartoon yourself using for example PowerPoint. If you want to do so, it’s important to have a good idea about the misconceptions your pupils have. Try to incorporate them into the concept cartoon.

Practicalities

Materials

CLASSROOM & REMOTE.

Each group should get the following:

- A room that you can darken as much as possible;
- A desk lamp (with 1 bulb) or a flashlight
- A vegetable/fruit bag OR a piece of tracing paper OR mosquito net

CLASSROOM.
If you use a normal classroom, you can use the beamer and the screen to make some investigations.

ICT components (app installation and testing)

CLASSROOM.
No ICT is needed for experimenting in person.

REMOTE.
First of all, you need a program to call each other and to make breakout rooms like Teams or Zoom.

A program that allows uploading photos and reporting conclusions like Google Jam Board or Mural is necessary for comparison of results and discussion within and between groups if worked remotely. It's also a good idea to have an easy program for making drawings, for example: *Paint*.

Grouping

CLASSROOM.
If you conduct the workshop in a normal classroom, you can create groups of 3 to 5 students.

REMOTE.
If all the students have the necessary materials, they can all work individually. If that's not the case they can be with 2 in one breakout room where one person supports the other one.

Setting

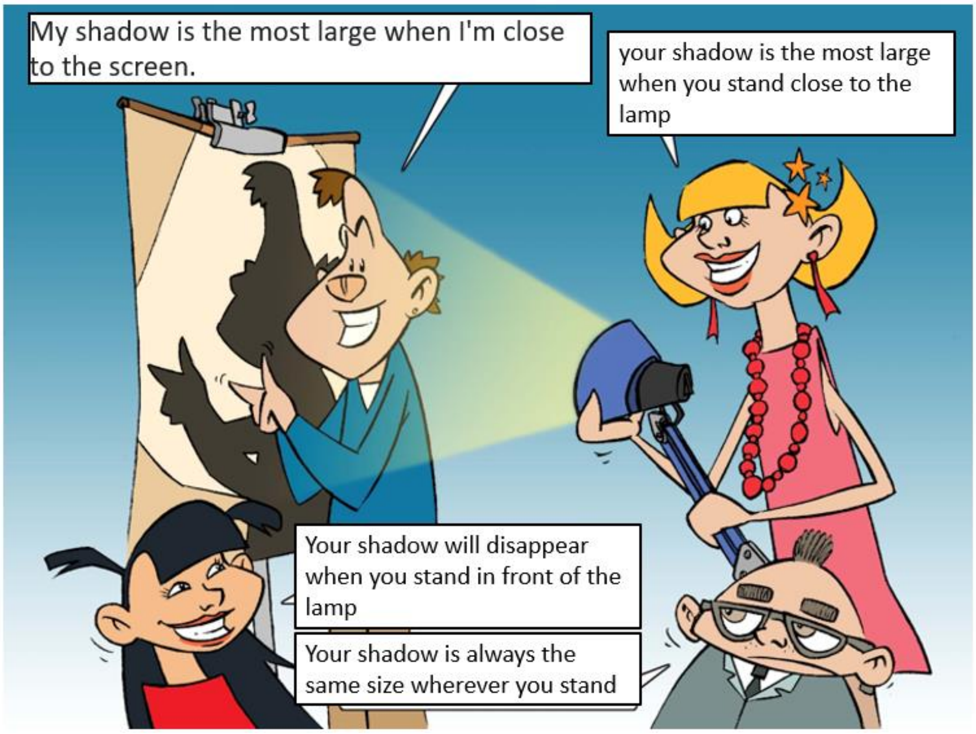
CLASSROOM.
Divide the group so they can work together with 3 to 5 students. Make islands with the benches in the classroom so that the groups do not disturb each other when performing the experiments.

REMOTE.
For the initial introduction of the task students are in the main room. Materials should be checked.

For conducting experiments – students are put in breakout rooms randomly, notes are taken on the *Jamboard or Mural* each group takes a separate slide.

IBL unit

PART 1. Concept cartoon 1 – Size of a shadow (20 min)



We start with a concept cartoon that we show for 30 seconds. We ask the students to vote. If this is online on Mural, they can vote without seeing the answers of the other students.

Watch the cartoon above and think **individually** about the following questions:

- *Which idea(s) is (are) similar to yours?*
- *Which answer(s) do you think is (are) correct?*
- *Why?*
- *Are multiple answers correct?*

This individual part is followed by a **group discussion & experiment**

Run through different answers to guidance questions:

- *What happens if we move closer to a light source with our hands?*
- *If you completely cover the lamp, can you still speak of shadow?*
- *Do you know situations where the size of the shadow doesn't change? How could that be?*

After the discussion, we go to the **answers**.

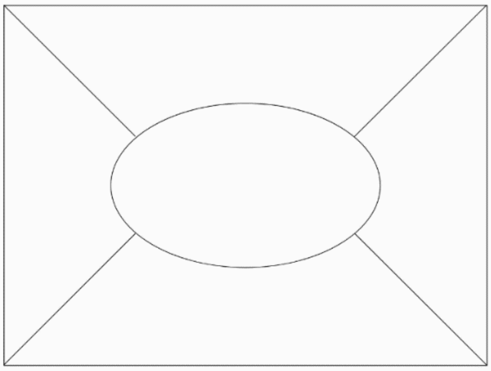
We ask the students to make some drawings of the different situations they've tested. For this drawings we use the rectilinear propagation of light. We can show the boundaries of the light beams with lines.

Examples of extra questions:

- *What if you completely cover the lamp?*
- *And what is the difference if you just turn off the lamp? (in terms of perception)*

PART 2. Concept cartoon 2 – Shadows at night (20 mi)

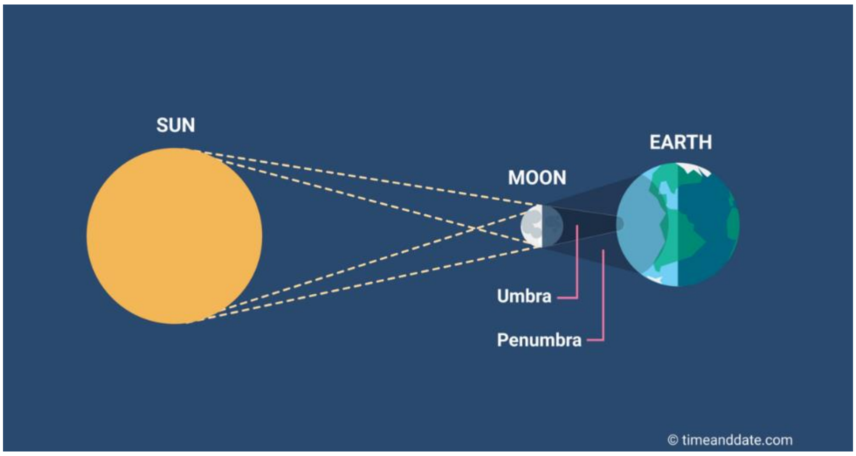
Let your students watch the cartoon above. Ask them to think with which idea(s) they agree with? (short individual). This time we ask them to write down their thought on some post-its on a placemat. This can be done online or in real life.



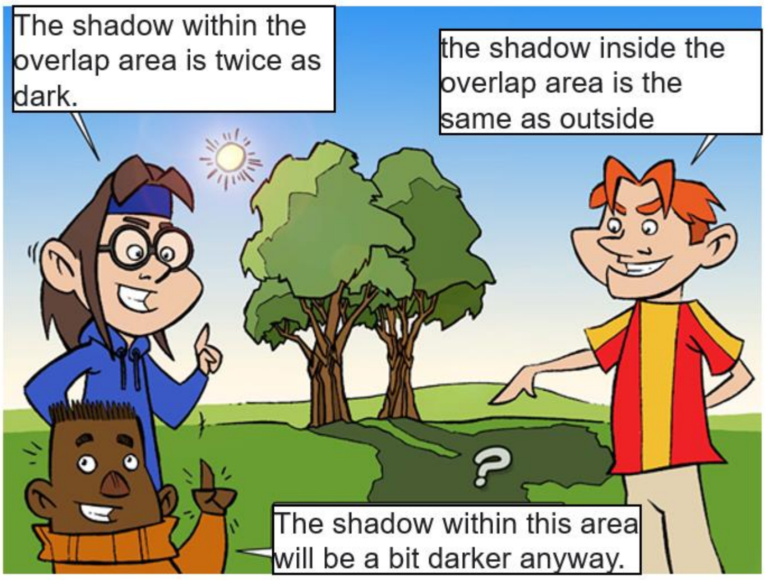
Each student gets a part of the placemat where they can write down their thoughts. They have to describe their points of view + arguments individually in their box (5min). After this the have an oral discussion with attention to arguments, examples, ...

When they agree on their answer, they write a group position (consensus) in the middle of the placemat.

After this part, it's a good idea to talk about solar eclipses.



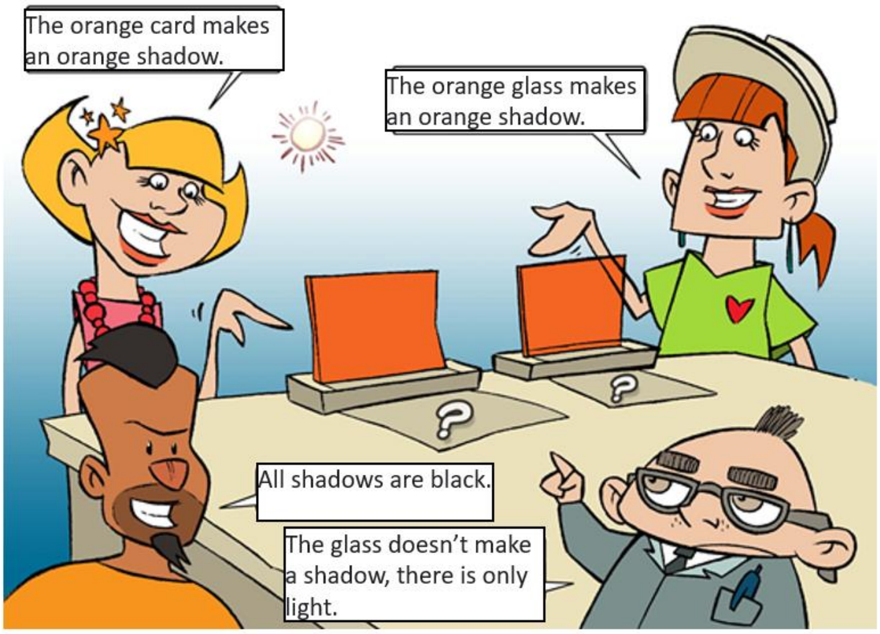
PART 3. Concept cartoon 3 – Overlapping shadows (30 min)



Let your students look at the cartoon above. *Which idea(s) do they agree with?* (short individual)

In break-out rooms, simulate various situations through simple experiments using a lamp, opaque (bar, stick), and translucent (tracing paper, gauze, etc.) objects. Give them time to really investigate themselves. Ask them to provide one spokesperson who will share conclusions later with the whole group.

PART 4. Concept cartoon 4 – Colored shadows (30 min)



This time we won't let the students vote at first. We first encourage the group to have a little discussion and then investigate the different ideas. They share, exchange, and present their findings. They try to link their findings to existing concepts and prior knowledge.

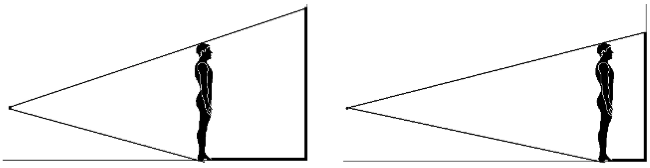
Physics behind

Concept cartoon 1.

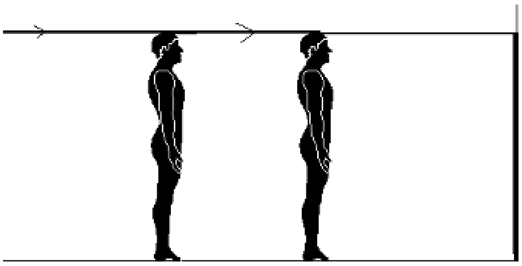
1. My shadow is biggest when I am close to the screen.

Your shadow is biggest when you are close to the lamp. Since these two ideas are diametrically opposed, they are discussed together. It would be unlikely if students identify with both ideas.

A brief experiment with an overhead projector and hands quickly shows that the shadow increases if you are closer to the light source. This is easily explained using the rectilinear propagation of light and diverging rays of light starting from a light source (nearby). See figure:



2. Your shadow is always the same size no matter where you stand.



When you use a beamer from the classroom, it soon becomes apparent that this is not true. The shadow of your hand is always enlarging and shrinking. However, an attentive student will notice that there is no enlargement of the shadow when you perform this experiment outside in sunlight, for example. This is because a distant light source creates a parallel beam. As a result, your shadow may indeed not enlarge. See rectilinear propagation of light.

3. Your shadow will disappear when you stand in front of the lamp.

This idea can be food for thought and is already a bit more difficult to explain.

If you were to cover the entire light source, basically the entire wall is covered with shadow. So the shadow does not disappear, but everything becomes shadow. The idea that the shadow "disappears" is due to the fact that one no longer has a clear boundary between light and shadow.

You can also rephrase the question. Suppose we cover the light source, so no direct light will fall on the screen (just some scattered light). Everything becomes shadow. But what is the difference if you were to turn off the light source? The perception would be identical. So in the first case you speak of shadow, in the second you don't. This already provides some food for thought on the nature of shadow. After all, when do you speak of shadow? So an appropriate description/definition is needed. A first attempt at defining shadow can already be given here (but is certainly not necessary).

In summary.

A prerequisite for shadow to occur is thus the presence of a light source and an object. This concept will be further explored and discussed in later cartoons.

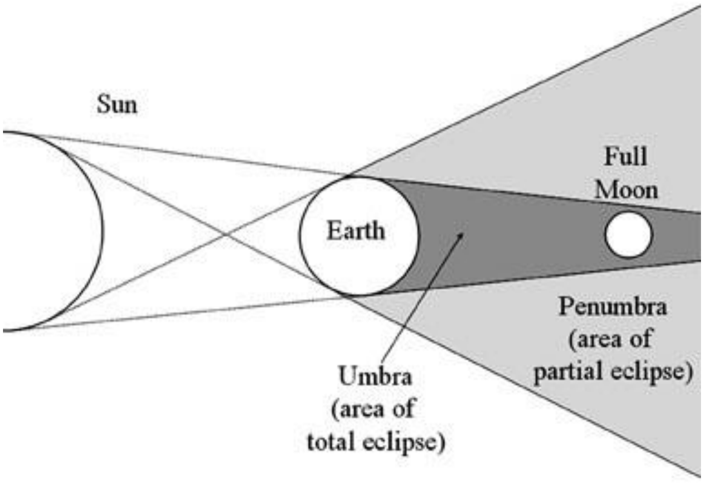
Concept cartoon 2.

Assume we have a dark night (cloudy sky, no other light sources). Let's go through each thought:

1. At night there are shadows, you just can't see them.

Students often have this image because they see shadows as objects in their own right. These 'objects' then become visible when we would light a light source.

However, you can look at the definition more broadly and say that everything is shadow (when you are in a pitch-dark room). This is discussed in answer 3.



2. At night, there are no shadows.

Shadows are associated with the presence of light in a particular place. If there is no light, there will be no shadows either.

3. Everything is shadow at night.

A drawing of our solar system gives a different view of night. After all, there is no light on the night half of the Earth because that part is precisely in the shadow cone of the Sun-Earth system. If you look at night in this way, you can in fact see night as one big shadow. It is not obvious to experience it this way because often a shadow is seen as one on a nicely outlined object (like the outline of your hand on a screen).

4. Shadows appear darker at night.

When there is a light source other than the sun (e.g. moonlight), shadows do appear. If you look closely, you will see that those shadows are darker than during daylight. This is because during the day there is more scattered light (i.e. light originating from different sources and its reflections).

Concept cartoon 3.

In this concept cartoon, we need to distinguish between 2 situations, one more complex than the other.

1. The shadow inside the overlap area is twice as dark.

Shadows are seen by students as self-contained objects. If you add two shadows together, you get a shadow that is twice as dark. They forget that a shadow is caused by the absence of (part of) light.

2. The shadow inside the overlap area is the same as outside it.

Of course, you can only remove light once, so the overlap of two shadows is as dark as the individual shadows. A simple experiment with 2 opaque light sources will quickly make this clear.

One possible answer students can formulate is that a shadow cannot be projected by another body. This seems plausible but poses another (philosophical) problem. After all, imagine the following situation and ask yourself: 'What kind of something is that dark spot inside the outline in the figure on the right?'

From the foregoing, it is clear that it cannot be the shadow of the table, since this shadow falls on the little guy and therefore cannot be projected through the little guy. Is that dark spot shadow, then? This problem also arises when we look at anti-shadow rules in certain metropolitan cities (see Tokyo story)[11].
Shadows owe their existence to light. Where there is no light, there are shadows. So shadows should not be seen as a stand-alone object.

3. Surely the shadow within this area will be slightly darker.

So here a slightly more complex situation presents itself. Depending on the density of the trees' leaves, the overlap area may still appear somewhat darker. The cause is that the foliage does let some light through. The double canopy will create a darker area. An experiment with slightly translucent material and a light source will quickly reveal this.

Summary.
We will have to define the description from the previous cartoon more generally. Indeed, shadow arises when the light from a light source is partially or fully blocked by an object.
In this situation, the concepts of light and shadow meet. Indeed, in the situation of shadow behind translucent bodies, one can ask the following question: 'What is that dark spot behind a partially translucent body: light or shadow?' This question is further addressed in the 4th concept cartoon.

---

[11] R. Casati, De ontdekking van de schaduw (The discovery of shadow), Amsterdam, Publisher ''The Bezige Bij', pg 72-74.

Concept cartoon 4.

Shadows are defined as the place where direct light from the light source does not reach. Since many see only 1 light source, shadows are usually considered black. The extreme case where there is no light at all on the shadow plane is rare. Just look at the shadows around you, they often take on the colour of the ground (e.g. on grass, the shadows are dark green). This means that light does reach this shadow spot. This light comes from multiple reflections or rebounds on surrounding objects and the atmosphere. For example, a lot of blue light still reaches the shadow spot in the white snow.

Many people see the orange spot behind the orange filter not as a coloured shadow but as coloured light. This is partly correct but you can also use the concept of shadow here. The filter blocks all frequencies of light except the orange frequency. This means that this filter actually creates a shadow for all 'non-orange' frequencies.

Shadows can actually be seen as light, and light can be seen as a shadow.

In summary:

1. All shadows are black: This is only correct if there is only 1 light source and no indirect scattered light.

2. There is an orange shadow behind the orange card: This notion is related to the confusion between light and shadow. However, the shadow can have an orange appearance in certain cases. Indeed, the reflected light from the orange card can reach the shadow zone in certain cases.

3. The orange filter has an orange shadow. The orange spot is the shadow of all 'non - orange' frequencies of (white) light.

4. There is no shadow behind the filter, only light. This is correct when you assume the concept of light. This is because the filter allows the orange frequencies of (white) light to pass through, forming an orange spot.

Conclusions

Concept cartoons use an activating form of work.

In addition to the objectives (both substantive and didactic), a distinction is made between activities and possible answers. The activities give a timetable of how the teacher guides and discusses the cartoon in question. The 'possible answers' section is a listing of all the possible answers the pupils could give. So this should not be seen as learning content to be given/discussed. The pupils ultimately decide which answers and decisions will be covered!

Credits: p. 130 The Moon's umbra, penumbra and antumbra (CC timeanddate.com), p.134 Lego shadows, own work (R. Putman);

Co-funded by the
Erasmus+ Programme
of the European Union

Subtle shifts

Teacher Guide

Reinout Putman
Jan de Lange

Teacher workshop – from structured to open inquiry

Introduction

This experiment is based on an experiment of the Exploratorium (San Francisco). We've made some small changes to give this workshop online.

The purpose of this experiment is to let teachers think about how they can make their lessons more experimental by making some little changes.

Curriculum topics

Subtle shifts can be used in lots of different lessons. This template will give examples for physics (shadows) and chemistry.

IBL level

This workshop shows different IBL-levels and how you can higher the level of IBL of a workshop.

Age of students

This workshop is made for teachers. Of course teachers can use the subjects we will show in their lessons but the shifts we want to show are more important here.

Practicalities

Materials

CLASSROOM & REMOTE.

Each group should have the following things:

- Resealable freezer bag
- Small plastic jar (e.g. medicine jar)
- Calcium chloride (CaCl2)
- Sodium bicarbonate (baking soda)
- 5 or 10 ml syringe
- 3 teaspoons
- Liquid diluted universal pH indicator. It is best to ask the chemistry teacher at your school for help here.
  For example: To prepare this dilution, add 1 litre of distilled water to 1 gram of phenol red and stir. Dilute with another 250 ml of water and mix again. Mix the phenol red beforehand and store in a plastic bottle, such as a soda bottle.

Teachers may be asked to bring their students' works for PART 7.

ICT components

REMOTE.

- A communication tool with a possibility to create breakout rooms like *Teams* or *Zoom*.
- A program that allows uploading photos and reporting conclusions like *Google Jamboard* or Mural is necessary for comparison of results and discussion within and between groups if worked remotely. It's also a good idea to have an easy program for making drawings, for example: *Paint*

Grouping

CLASSROOM.

If you conduct the workshop in a normal classroom, you can create groups of 3 to 5.

REMOTE.

If all the teachers have the necessary materials, they can all work in random groups. If that's not the case you should make groups where there is at least one teacher who has all the materials.

Setting

CLASSROOM.

Divide the group so they can work together with 3 to 5 teachers. Make islands with the benches in the classroom so that the groups do not disturb each other when performing the experiments.

REMOTE.

For the initial introduction of the task teachers are in the main room. Materials should be checked. For conducting experiments – teachers are put in breakout rooms randomly, notes are taken on the *Jamboard or Mural* each group takes a separate slide.

The teacher IBL workshop

PART 1. Inductive or deductive (5 min)

We start the workshop with a bit of theory about inductive or deductive lessons.

Exploratory or inductive research process	Verifying or deductive research process
• A 'fascinating' observation • Systematic research through prolonged observations, examining influencing factors, ... • Result a coherent description or model of the phenomenon	• Assume that the hypothesis is true • Predict the outcome of different experiments • Check these predictions experimentally

Each of these ways of shaping your lessons has its strengths. It is especially important as a teacher to think about it and offer variety to your students. Some examples are given for each process. This is all done in the main room with all the teachers together.

PART 2. Investigation 1 (20 minutes)

First of all, check that all teachers have all the necessary materials. If not, make your groups so that in each group there is at least one teacher who already has the necessary materials with him. The teachers work together in groups of four. They describe all the changes they can perceive with their senses. Only they are not allowed to taste.
This part of the workshop is done in little groups or breakout rooms.

Main questions

- *Did a chemical change take place or not? (How is this different from a physical change?)*
- *How can you observe this?*

The document for the teachers can be found at the end of this module. Take the 'shifted' workshop first.

Part I **Exploration**

Observation

Part II **Hypothesis testing**

Option A (influence substances)

Option B (influence quantities)

After the investigation itself, the teachers share their ideas and have a short discussion.

PART 3. Reflection on investigation 1 (10 minutes)

1. All teachers come back to the main room. Each group fills in the table below.
2. Pupil or teacher, who decides?
    - Left: teacher a minute role
    - Right: pupil a minute role
    - Middle: both equal
3. Distinguish between:
    - Asking the question or defining the problem
    - The process
    - The results/decisions

	Learner	**Teacher / Learner**	**Teacher**
Who determines the question/problem?			
Who determines the procedure/design?			
Who determines the results/analysis?			

4. By doing this, teachers will think about their role and the role of the pupils.
5. Ask the teachers how did they experience the assignment. Let them write down some thoughts on a paper or a *Mural* or *Miro-board*.

PART 4. Investigation 2 (20 minutes)

The teachers will now do a quite similar investigation. The worksheet can be found at the end of this document. Now take the 'unshifted' version. The teachers work again in the breakout rooms. Should you really run out of time, you can also just let the teachers read the assignment.

PART 5. Reflection on investigation 2 (15 minutes)

All teachers come back to the main room. Let them write down on the Mural or Miro-board what they think is different about the two versions.

In this reflection we focus on the changes between the two versions of the workshop sheets. Have a little discussion about this. We've listed some things we see as the differences.

Changes:

- Instructions are more open-ended
- Pupils have to organise their own data
- Learners can choose what exactly to investigate
- Learners are asked to indicate for themselves what they important/relevant
- You don't feel there is 1 right answer.
- Expect pupils to have new questions

PART 6. Advantages (5 minutes)

Let the teachers think about the version they liked the most as they run the workshop as a student but also let them think what they would like to do as a teacher the most. Ask them to give arguments why they prefer one version over the other. We've listed some of the most frequent arguments:

- Decisions need to be argued
- Pupils get freedom in how they write down and forces them to reflect on it.
- Learners don't know what to look at. Challenges them to observe it more closely
- Higher-order skills are activated by having to interpret and analyse what they observe.
- Pupils must first write down observations accurately themselves, analyse them and formulate their own decision.
- Pupils have greater ownership of what they do.- Pupils are encouraged to make their own discoveries- Being given opportunities gives students self-confidence
- Students have to think for themselves and ask new questions
- By making their own predictions, students are more engaged.

It's possible that some teachers prefer the workshop where the teacher has the most control. Especially for students who need a lot of handholding, this will often be the chosen version.

However, if we look at the students' inquisitive attitude, the first version will emerge as the winner. We want to show with these 2 versions that by making small changes to your assignment, you can engage in a lesson with your pupils in a much stronger investigative way.

This is not a call to give students who are used to getting very clearly delineated assignments a completely open-ended assignment. In fact, the chances of them dropping out on this are quite high. What we do try to achieve is that teachers start thinking about whether they can make small changes to open up an assignment and let students discover more on their own. Ideally, there is some kind of learning line in this where students are prepared to deal with fully open-ended assignments.

PART 7. Work with own material (20 minutes)

It is perfectly possible to finish the workshop with the above reflection. However, it is recommended to immediately put your money where your mouth is and get to work with materials teachers have brought along.

Again, divide your teachers among the breakout rooms and have them each present a practical or small bundle. Let them explore together what small adjustments you can make to let students take more ownership of the investigation.

Ideally, the same group of teachers will meet again after a month or two to discuss together the lessons with adjustments and think about other possible adjustments to upcoming lessons.

Physics & Chemistry behind

It is difficult to always quickly determine whether a reaction is physical or chemical. If you are only going to keep an eye on physical factors such as volume, it is difficult to make any statements about this. However, if you start from a chemical point of view, it is a little easier to make a statement. In a chemical reaction, the connections between atoms change to form new substances. This is accompanied, for example, by a difference in temperature as heat is created or withdrawn, the color or smell of the substance may change, etc. If the pH of the substance changes, then you are also definitely dealing with a chemical reaction. Hence, we have conducted a pH test here. We used a universal indicator for this purpose.

Universal indicator

pH range	Description	Colour
< 3	Strong Acid	Red
3-6	Weak Acid	Orange/Yellow
7	Neutral	Green
8-11	Weak Base	Blue
> 11	Strong Base	Violet/Purple

(Universal indicator, 2023)

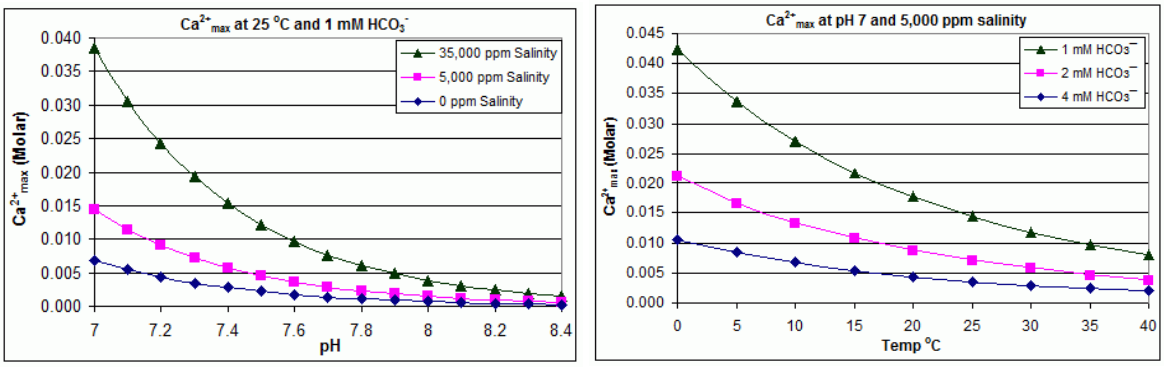
Such a universal indicator is a pH indicator made of a mix of different compounds that changes in color when the pH value changes.

Reaction

The reaction equation of the reaction that took place in our experiments is the following:

$$2\ NaHCO_3\ (ag) + CaCl_2\ (aq) => CaCO_3\ (s) + H_2O\ (l) + CO_2\ (g) + 2\ NaCl\ (aq)$$

This means that $CaCO_3$ has formed but a part of this dissolves in acidic water. The graphs below show the solubility of calcite.



(*Calcium carbonate*, 2023)

Calcium carbonate has a very low solubility in pure water (15 mg/L at 25°C), but in rainwater saturated with carbon dioxide, its solubility increases due to the formation of more soluble calcium bicarbonate. (*Carbonate chemistry*, 2023)

References

Calcium carbonate. (2023, october 27). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Calcium_carbonate

Carbonate chemistry. (2023, october 27). Retrieved from Science learning hub: https://www.sciencelearn.org.nz/resources/469-carbonate-chemistry#:~:text=Calcium%20carbonate%20has%20a%20very,temperature%20of%20the%20water%20decreases.

Facilitators Guides. (2023). Retrieved from Exploratorium: https://www.exploratorium.edu/ja/node/4104

Universal indicator. (2023, October 27). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Universal_indicator

Credits: p.136 Light Bulbs, Levent Simsek, Free Stock Photos Pexels; p. 138 own work (R. Putman) Syrengie, public domain , Wikipedia; p. 139 Photos from AHS remote workshops, own work (R. Putman); p. 142 (upper) Universal indicator, Dejan Jovic, CC BY-SA 4.0, Wikipedia; (down) Calcium carbonate, autor: R Ge B, CC BY-SA 3.0, Wikipedia

Worksheets from the Exploratorium

Changes Activity (Shifted)

In this activity, you'll try to determine whether or not a chemical change has taken place by investigating the question, "What indicates the occurrence of a chemical change?" Careful observations will help you gather evidence.

Exploration: Part I

Read all of Part I. Then design a data-collection sheet on which you can record what you do and what you observe. Be sure that it is in a format that is easy to follow and can be shared with others. Then do the activity.

- Put on your safety equipment.
- Place ¼ teaspoon of sodium bicarbonate ($NaHCO_3$) and ½ teaspoon of calcium chloride ($CaCl_2$) into a ziplock bag.
- Fill a medicine cup with 5 mL of phenol red solution. Carefully place the cup in the bag, keeping it upright until after you zip the bag closed.
- Squeeze out as much air as possible and seal the bag.
- Keeping the bag sealed, tip the cup over, mix the chemicals together, and observe the result.
- Record what you did and what you observed on your data-collection sheet. Record the evidence you think indicates a chemical change.

Exploration: Part II

Choose Option A or Option B (below) to continue your investigation. Design a new data-collection sheet for that option. Complete the second option if time permits, using another data collection sheet.

OPTION A

- Predict what would happen if you tried the experiment again but left out one of the chemicals.
- Test your prediction. Record what you did and what you observed.
- Repeat this experiment, leaving out a different chemical.

OPTION B

- Predict what would happen if you varied the amount of one of the chemicals.
- Test your prediction. Record what you did and what you observed.
- Repeat this experiment several times, each time varying a different chemical.

Summary

1. Analyze and summarize the results of your experiments on your data-collection sheets.
2. List any questions you still have on your data-collection sheets.
3. Describe what you have discovered about chemistry from this activity.

Adapted from an activity created by the Earth System Implementation Project of Anchorage, Alaska. Presented at the Kits to Inquiry Graduate Seminar at the Exploratorium's Institute for Inquiry, March 1999.

Changes Activity (Unshifted)

In this activity, you'll experiment with chemical reactions that take place in a ziplock sandwich bag. The sealed bag prevents any chemicals from escaping before you have a chance to observe the reactions.

Chemists gather evidence by observing. A chemical detective watches out for these four indicators (among others) of a chemical reaction:

change of color
change of temperature
formation of solids
formation of gases

A good chemist must be careful and take the time to look for each of these kinds of evidence.

Procedure

- Put on your safety equipment.
- Place ¼ teaspoon of sodium bicarbonate ($NaHCO_3$) and ½ teaspoon of calcium chloride ($CaCl_2$) into the ziplock bag.
- Pour 5 mL of phenol red into the medicine cup.
- Place the cup carefully in the baggie so that it stays upright, squeeze out as much air as possible, and seal the bag.
- Tip over the cup and mix the contents together.

Use the back of this sheet if you need more room to record your observations and discoveries.

Questions

1. Write detailed observations of the changes you see.____
____
____
____

2. What evidence have you gathered that a chemical reaction took place?______________________________

____
____
____

3. Predict what would happen if you left out the calcium chloride ($CaCl_2$). Try the experiment again, make careful observations of the changes you see and record them below. Predict what would happen if you left out the sodium bicarbonate ($NaHCO_3$). Try this, and record your observations and results.

____
____
____

4. What happens when you use ⅛ teaspoon of sodium bicarbonate ($NaHCO_3$)? What if you use 1 teaspoon of calcium chloride ($CaCl_2$)? Record everything that happens and the amount of each chemical added.

____
____
____

5. What have you discovered about chemistry from this experiment?___________________________________

____
____
____

Adapted from an activity created by the Earth System Implementation Project of Anchorage, Alaska.
Presented at the Kits to Inquiry Graduate Seminar at the Exploratorium's Institute for Inquiry, March 1999.