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3DiPhE
Three Dimensions of Inquiry in Physics Education

INQUIRY BASED LEARNING TO ENHANCE TEACHING

Theory, tools and examples

1

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Volume 1: Inquiry Based Learning to enhance teaching

Theory, tools and examples

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Erasmus+

3DiPhE Three Dimensions of Inquiry in Physics Education

ABOUT THE PROJECT:

The ERASMUS + Project KA2 2017-1-SI01-KA201-035523 Three Dimensions of Inquiry in Physics Education (2017-2020) focused on commonalities and differences between inquiries at three different levels and the final results are comprised in an e-book in four volumes. These dimensions are.

- Inquiry by students who use the inquiry-based learning approach to learning physics;
- Practitioner inquiry of teachers inquiring the processes in their classrooms;
- Inquiring processes in collaborative professional learning communities of teachers; and in addition
- Inquiring and evaluating all processes in the project using educational design research.

The project actively involved seven partners from four different countries (Slovenia, Belgium, Ireland, Poland), more than one hundred teachers from all partner countries and indirectly more than one thousand students taught by these teachers. The acquired knowledge was shared with several teachers who were not involved in the project and we hope that they will benefit from the presentation of our results in these volumes.

Mojca Čepič, the project leader

GLOSSARY

This refers to the glossary of definitions for the purposes and context of the 3DIPhE project.

Title	Description
Professional Learning Community	A professional learning community is considered to be a group of teachers and/or educators working together in a supportive, collaborative and positive environment. It is characterised by a shared vision, responsibility and values, and equitable participation.
Practitioner Inquiry	Practitioner Inquiry refers to the professional learning of coaches, teachers/educators who are engaged in a planned study on their practice leading to recommendations enabling evidence informed changes
Inquiry Based Learning	An active learning method in which students, in order to develop knowledge or find solutions (e.g. to discover trends, measure quantities of objects or quantities related to phenomena, find out the limits etc.), follow a scientific method used by researchers in science studies. IBL emphasizes the students' role in the learning process in which they are encouraged to explore the scientific issues, ask questions, and share ideas. Instead of memorizing facts and rules students discover them by doing. The teachers' role is to support students in their learning process, and not to instruct them.
Educational Design Research	Educational Design Research (EDR) is an iterative process where learning is systematically studied in the context in which it happens. The EDR process allows researchers and educators (often the user of EDR acts as both) to design, develop and evaluate educational programmes and interventions. By systematically studying this development, the EDR process can generate knowledge and theory relevant to the educational settings in which it is used.
Cycle	A clearly defined phase of the project in the context of the EDR Framework.
Iteration	This refers to the implementations of the PLCC and PLCT courses during the 3DIPhE project. These happened during Cycle 3 and Cycle 4 of the EDR framework.
Partner	Partner institution or its representative that is officially involved in the project.
Coach	Individual who designs, organises and guides activities in professional learning communities.
Facilitator	Individual who facilitates an activity or protocol as part of a workshop. A facilitator can be a coach or teacher in a workshop.
Participant	Individual attending an event e.g. course, conference, meeting,... This can refer to partners, teachers, future 3DIPhE coaches or external stakeholders
Teacher	In-service teacher who practices in a formal school setting
Student	Child, aged 10-18, in a formal school setting
Course	A coherent set of workshops aimed at a targeted learning process for participants
Workshop	A single meeting of a course with clearly defined goals.

Tool	A specific teaching and learning material used by coaches and teachers
Activity	A general noun for a part of a workshop where some action takes place, e.g. following a protocol, group discussion, watching an instructional video, etc. An activity is more general than protocol.
Protocol	A set of instructions, used during a workshop, with clearly defined goal(s), that has a strict order of actions and timing of those actions.
Worksheet	A learning support material e.g. used by participants of workshops or students in a classroom.
IBL Unit	A collection of inquiry based learning activities centred around a theme, topic or concept.
Information sheet	Additional background information to support an activity.
Course Guide	A guide book for coaches that details the structure, activities and rationale for planning and implementing a course.
Course Workbook	A complete collection of all teaching and learning materials that is used by participants of a course.
Inquiry	Inquiry (IBL): In the context of Inquiry Based Learning, inquiry refers broadly to the activities that students carry out in the classroom. Inquiry (PI): In the context of Practitioner Inquiry, inquiry refers to the planned study that coaches, teachers/educators carry out in the context of their own practice.

Table of Acronyms

Professional Learning Community	PLC
Professional Learning Community of Teachers	PLCT
Professional Learning Community of Coaches	PLCC
Practitioner Inquiry carried out by a teacher	PIT
Inquiry Based Learning	IBL
Education Design Research	EDR
University of Ljubljana, Faculty of Education, *Slovenia*	UL
Jagiellonian University in Kraków, *Poland*	UJ
Dublin City University, *Ireland*	DCU
Catholic Education Flanders – vzw VSKO, *Belgium*	CEF
Artevelde University College, *Belgium*	AHS
UC Limburg, *Belgium*	UCLL
National Education Institute, *Slovenia*	NEI

CONTENT

PART A:
INQUIRY BASED LEARNING

CHAPTER 1:
What is IBL?

1.1 INTRODUCTION

Education should serve as a platform for human being development and growth here and now and in the perspective of the next 10-30 years. Although in a fast changing world one cannot anticipate anymore the challenges people will face throughout their whole life, education should not provide anymore only the state-of-the-art knowledge, but should take into consideration development of skills and attitudes towards self-learning and self-development in order to equip students in tools and strategies that enable students to carry on their education after leaving the school system.

Despite decades of intensive research in education, and in particular – in science education, contemporary schooling almost all over the world is in general still focused on "learning to test", which basically means learning only the so-called hard competences, easy to measure, with a clear advantage of purely informational knowledge over deeper understanding and practical skills, and bypassing soft competences, such as the ability to cooperate in a group. This type of education is based on a message limited to two perception channels: visual and auditory, with neglect of other human senses. The most common way of teaching is dictating notebook notes with the intention of verifying the acquisition of their content, preferably in a literal form, or "by heart" and not necessarily with understanding. The creator of the theory of multiple intelligences - H. Gardner - sees the pattern of such behavior in the history of scholasticism and the Middle Ages, when education was inseparably connected with religion, and science consisted in learning a set canon of knowledge by heart and repetition of content[1].

> The pattern of *learning by heart* originates from Middle Ages when education was inseparably connected to religion and science was limited to a canon set of facts and rules

> Contemporary education focuses on development of competences, as a combination of: content knowledge, skills and attitudes

However, the modern world, with its enormous pace of change and the need to constantly adapt to dynamically changing conditions to meet previously unknown challenges, puts a man entering adult life with requirements and goals, the implementation of which becomes difficult without the key competences formed in the education process. And these are now understood as an inseparable combination of knowledge, skills and attitudes in eight key areas[2].

Since the modern world is increasingly dependent on exact, natural and technical sciences, there is a growing need to attract people who would associate their future and professional career with the development of these areas of life. Thus one of the eight key areas of competence mentioned above is to provide basic education in natural and exact sciences. 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

[1] H. Gardner (2006), *Five minds for the future*, Boston, Mass.: Harvard Business School Press, Harvard 2006, p. 33.
[2] EU Key Competences for Lifelong Learning (2006), adopted in 2018. Retrieved from: https://op.europa.eu/en/publication-detail/-/publication/297a33c8-a1f3-11e9-9d01-01aa75ed71a1/language-en

life in motivating and teaching them. In accordance with a document, called in short Rocard's Recommendation[3] (2007), the best teaching strategy in this area is the inquiry-based learning method.

Inquiry-based Learning (IBL) is an active learning method in which students, in order to develop knowledge or find solutions (e.g. to discover trends, measure quantities of objects or quantities related to phenomena, find out the limits etc.), follow a scientific method used by researchers in science studies. IBL emphasizes the students' role in the learning process in which they are encouraged to explore the scientific issues, ask questions, and share ideas. Instead of memorizing facts and rules students discover them by doing. The teachers' role is to support students in their learning process, and not to instruct them.

When speaking about inquiry-based learning we think about creativity, enhancement of critical thinking and reasoning, and development of research skills on the basis of learners' curiosity and inquisition.
Unlike traditional teaching, inquiry-based learning is student-centered, consequently leading students to gain more and more independence in learning. IBL involves thorough and deep thinking, action and authentic engagement of learners, thus stimulates and reinforces all three domains of human development: cognitive, psychomotor and affective. In other words IBL supports development of competences, seen as a combination of content knowledge, skills and attitudes. [4]

IBL is one of the the best methods to build competences in science

The method of IBL, due to the fact that on the one hand it provides a high level of knowledge transfer[5], and on the other hand - it creates opportunities for the development of practical skills, as well as the increase of interest and motivation of students, seems to be the best method of teaching science and building competences specific to it.

[3] 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
[4] EU Key Competences for Lifelong Learning (2006), adopted in 2018. Retrieved from: https://op.europa.eu/en/publication-detail/-/publication/297a33c8-a1f3-11e9-9d01-01aa75ed71a1/language-en
[5] D. Sokołowska (2018), *Effectiveness of learning through guided inquiry*, in: *The Role of Laboratory Work in Improving Physics Teaching and Learning,* D. Sokołowska, M. Michelini (eds.), p. 243-255.

1.2 GENESIS

Inquiry-based learning (IBL) can be defined as a process of constructing knowledge through direct experience in authentic environments. The idea of such an approach originated from the works by founders and influencers of constructivism, a theory in education that recognizes the learning as done by students who "construct" knowledge out of their experiences.

Jean Piaget (1896 – 1980)
(phot. Wikipedia)

Jean Piaget laid down the course of education, saying:

The principal goal of education in the schools should be creating men and women who are capable of doing new things, not simply repeating what other generations have done; men and women who are creative, inventive and discoverers, who can be critical and verify, and not accept, everything they are offered. [6]

Lev Vygotsky (1896 – 1934)
(phot. Wikipedia)

Lev Vygotsky argued:

It must not be forgotten that the basic law of children's creativity is that its value lies not in its results, not in the product of creation, but in the process itself. It is not important what children create, but that they do create, that they exercise and implement their creative imagination. [7]

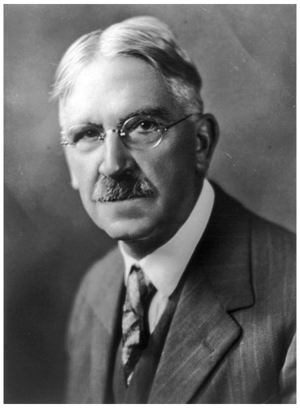
John Dewey (a principal figure in progressive education) persuaded:

Give the pupils something to do, not something to learn; and the doing is of such a nature as to demand thinking; learning naturally results. [8]

He used, probably for the first time, the word inquiry in education:

Scientific principles and laws do not lie on the surface of nature. They are hidden, and must be wrested from nature by an active and elaborate technique of inquiry. [9]

and developed the model of learning known as "the pattern of inquiry"[10].



John Dewey (1859-1952)
(phot. Wikipedia)

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[6] *Education for Democracy, Proceedings from the Cambridge School Conference on Progressive Education* (1988) edited by Kathe Jervis and Arthur Tobier

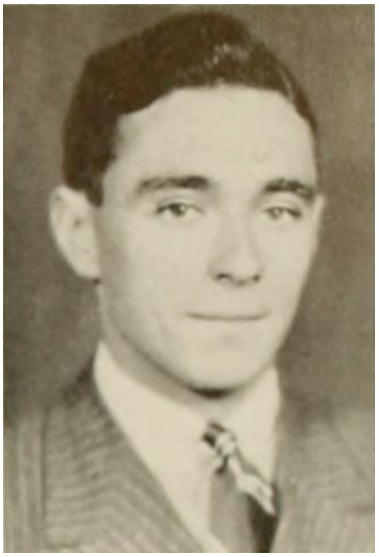
[7] L. Vygotsky (2004) *Imagination and Creativity in Childhood*, (translation into English from Russian: *Journal of Russian & East European Psychology*, 42 (1), 7-97

[8] J. Dewey (1966), *Democracy and Education*, Ch. 12 *Thinking in Education*. New York: Free Press

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

[10] J. Dewey (1938), *Logic, the theory of inquiry.* New York, H. Holt and Company

Finally the concept of inquiry-based teaching was reinforced in early 1960s, introduced independently by Schwab (1960) and Bruner (1961):



Jerome Bruner (1915 – 2016)
(phot. Wikipedia)

… intellectual activity anywhere is the same, whether at the frontier of knowledge or in a third-grade classroom. What a scientist does at his desk or in his laboratory, what a literary critic does in reading a poem, are of the same order as what anybody else does when he is engaged in like activities – if he is to achieve understanding. The difference is in degree, not in kind. The schoolboy learning physics is a physicist, and it is easier for him to learn physics behaving like a physicist than doing something else. The "something else" usually involves (…) classroom discussions and textbooks that talk about the conclusions in a field of intellectual inquiry rather than centering upon the inquiry itself. Approached this way, high school physics often looks very little like physics, social studies are removed from the issues of life and society as usually discussed, and school mathematics too often has lost contact with what is at the heart of the subject, the idea of order. [11]

1.3 IBL CYCLE

Dewey's original "pattern of inquiry" consisted of five steps:
1) Become aware of the problem.
2) Define the problem.
3) Propose hypotheses to solve it.
4) Evaluate the consequences of the hypotheses from one's past experience.
5) Test the likeliest solution.

IBL teaching & learning strategy is built upon a learning cycle implemented at different levels.

The idea evolved into a more extended cycle (Fig.1), forming a unit of a learning process. The unit is complete, thus closed, in the sense that it mimics the entire unit of scientific process of research, but at the same time the unit is open for taking a subsequent step in order to extend the problem. The IBL cycle repeated frequently, builds the process of the learner's development. However the cycle should not be treated as a rigid structure and should be implemented regarding the learning purpose and class circumstances.

[11] J. Bruner, (1960), *The Process of Education*, Harvard University Press, Cambridge Massachusetts, London England (1960), p. 14

Fig. 1 IBL cycle

The work cycle of inquiry-based learning consists of several stages.

1. **Setting the scene and generating ideas** on a certain topic or problem initiates the whole process. At this stage a general topic is selected, most often a phenomenon, or the question arises: why does this happen? or why something takes this form and not another? The issue may be related to the topic resulting from the curriculum or appear on the initiative of students interested in some observation or their experience. If this is the teacher's theme, it not necessarily needs to be directly communicated to the students - it can remain a mystery, revealed to and by students during the brainstorming, in order to arouse greater interest of students in the topic of classes.

   Generating ideas usually begins with a 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 through this stage 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 important for three reasons. First of all, it is supposed to introduce two very important 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, including those generally perceived low achievers (on the basis of the content-knowledge-based tests), can speak spontaneously. Thirdly, this is the phase in which the teachers learn what is 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 last moment for adjusting the subsequent process.

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 in such a way 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.

3. The corollary to formulating the inquiry question is to **put forward hypotheses/predictions** on the outcomes of the experiment. In some cases, it occurs just after formulating the inquiry question, in others - after establishing an action plan, but always before students proceed to the investigation as such. At this moment learners brainstorm again, either individually, in pairs or in groups about possible outcomes. Preferably they come with their hypothesis, reasoning on the basis of their knowledge and experiences. This reflection that appears before performing the experiment is of great importance at a later comparative stage, in which intuition is confronted with the objective results of the experiment. In many cases at this stage the teacher can figure out misconceptions they have. However it can also reveal learners' creative ideas on the specific topics.

4. **Planning investigation** is the next stage of work organization.
   - Research groups are created and the division of roles is established by selecting the members who will directly conduct the experiment, the person who will take notes, the students who will carry out data analysis, as well as the person responsible for the subsequent presentation of the results. Depending on the complexity of the issue and the number of groups, one student may be responsible for several activities. The teacher's task is to supervise the division of roles and to ensure that in many IBL cycles throughout the school year learners will change their roles so that each of them can test themselves in different tasks, finding out their weaknesses and strengths.
   - At this stage, students decide on the selection of materials, tools and instruments necessary to conduct the experiment.
   - One of the important elements of the design is to determine the order of activities, i.e. to prepare an action plan. However, it should be noted that the formalism of this task should not outweigh its desirability, especially at the lower stages of education. For younger learners or learners not experienced in IBL, the design stage may involve a trial-and-error approach of planning, first trial, redesign of the plan, the second trial and so on. In such cases the ultimate plan can emerge after completing the investigation.

5. **Carrying out the investigation.** After making a hypothesis and setting an inquiry plan students perform one or more experiments, recording their observations and experimental data. In any IBL cycle teacher's role at this stage is just to observe students at work and intervene only in an emergency issue.

6. **Data analysis** - after completing all stages of the experiment, students organize their notes and then conduct an analysis of experimental data and observation. At this moment learners employ knowledge and skills of data analysis and visual representation of data or search for such information on the internet or by asking a teacher.

7. On the basis of the elaborated results students **draw conclusions**, trying to answer the inquiry question. During the initial summary, students return to the hypotheses put forward at the beginning of the third stage and

confront them with the results of the experiment. While drawing conclusions, learners combine information from all phases of the experiment (or several experiments carried out in the fifth stage), and formulate conclusions combining the collected results. On their basis, students attempt to answer the inquiry question, verbalizing supporting arguments. At the final step of this stage, students critically analyze the correctness of conducting the experiment and draw conclusions regarding the possibility of improving the inquiry plan. Data analysis might lead them to other interesting problems they would like to investigate in the future.

8. **Sharing the results** obtained in individual groups is used to present and compare the outcomes and procedures. On one hand, students learn to present inquiry results in a clear and consistent manner within a given time frame, and on the other, to ask constructive questions to other research groups. If students answer the same inquiry question in different groups, they can compare their solutions. In case of different groups performing a different experiment in the scope of one global study (e.g. checking the impact of various factors on the same phenomenon), students will learn about the results from other groups, each of them complementing only a single aspect of the study in their own group. In this way, not only knowledge based on direct, own experience, but also knowledge resulting from the experience of others is built. Learners have the opportunity to look at one solution in a broader context and learn to look at the same issue in different aspects. Learner confidence and the ability to relate to the results of work of the others are developed in this way. Here also, a few moments are usually devoted to taking coherent notes, just to ensure that no student is left without notes or with incorrect conclusions.

9. **Developing the problem** is a closing phase of the IBL cycle and at the same time a stage with the potential to open the next inquiry cycle. Enriched by the experience gained in the ending cycle, students broaden their interest in the subject, think about subsequent phenomena and experiments, and formulate new issues.

Each stage of the IBL cycle is characterized by specific time requirements, its own dynamics and principles of group management. The first stage starts with the teacher and develops through a brainstorming or interactive story-telling, usually lasting no more than ten minutes. Asking an inquiry question prepared by the teacher himself takes less time than when formulated by students. Putting forward hypotheses, designing and conducting experiments are the most time consuming. Students work in teams, hence the high dynamics of these stages and the challenge for the teacher to manage many groups at once and maintain work discipline. Summary results and conclusions take less time, but require more analytical and critical thinking on the part of students. The presentation of the results of one group should be short, but it needs to be remembered to provide sufficient time for each group to speak up and leave room for constructive evaluation by other groups. This phase of listening to each other, requires increased focus and a relatively quick response when formulating the criticism. Students learn how to become critical friends, respecting each other. The last stage can be an individual or group reflection on the entire ending cycle of work - a task to be performed during classes or homework, therefore its dynamics will depend on the form chosen by the teacher.

IBL cycle is flexible

It is worth to notice that the work in the IBL cycle is somewhat flexible. Sometimes it runs smoothly from the first to the ninth stage. Naturally, however, the possibility of developing stages occurs when the issue is more demanding due to the degree of complexity or lack of experience of students in working in this method. It is conceivable that after the fifth or even the sixth stage, students who are not satisfied with the experiment may return to the fourth stage to design a modified experiment. Flexibility also applies to skipping certain stages (eighth or ninth), especially at lower levels of students' proficiency in working with this method.

It should be also remembered that the goal of the IBL activity not always comprises the acquisition of content knowledge. In some activities the aim might be mostly to develop practical skills or even only to enhance soft skills, e.g. collaboration or positive attitudes, e.g. sense of responsibility or interest in science.

1.4 IBL LEVELS

Responsibility for the implementation of individual stages of the cycle is divided between the teacher and students, and the only phase that they always go through together is the first stage. The less the teacher intervenes, the greater the independence of students working with the IBL method and the higher their level of proficiency in applying this method.

Three distinguished approaches to inquiry instruction, called IBL levels can be used, namely structured inquiry, guided inquiry and open inquiry[12]. In **structured inquiry**, the teacher sets up a hands-on problem for students to investigate, and provides procedures and resources, but does not inform them of expected outcomes. In **guided inquiry**, the teacher sets up a problem to investigate and provides resources, but s/he also allows students to devise their own procedures to solve the problem and draw conclusions, and only support them in data analysis. In **open inquiry,** the students select their own problems, set up the inquiry questions by themselves, search for resources, plan procedures and work out solutions, all by themselves. Yet, concerns are raised regarding whether all levels of students have the capabilities to do inquiry learning to develop conceptual understanding without scaffolding. [13]

The higher the level, the more independent the student is from the teacher and his or her instruction.

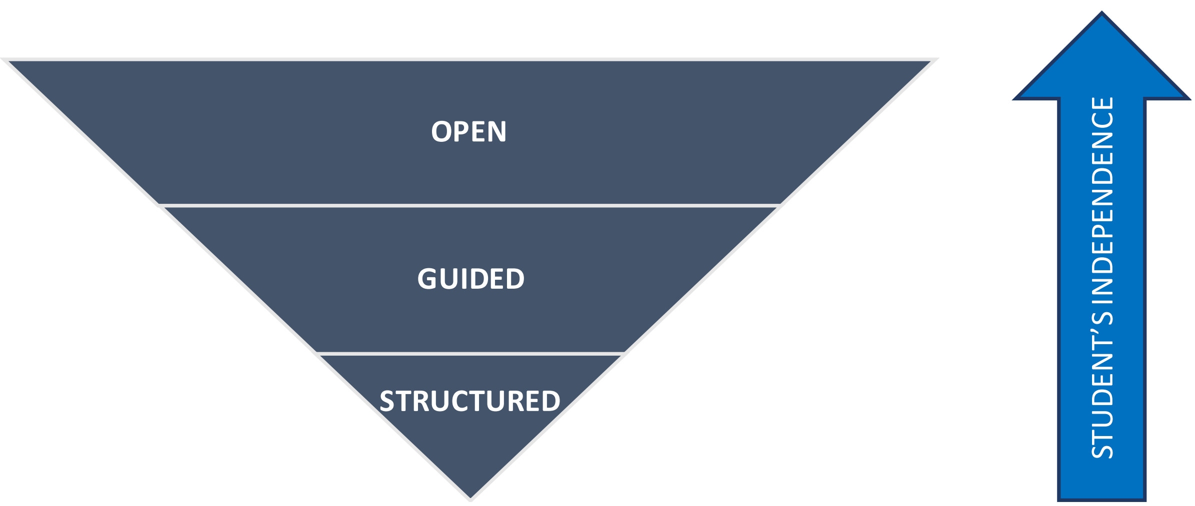


Fig. 2 IBL levels

[12] A.Colburn (2000). *An inquiry primer.* Science Scope, 23, 42–44

[13] Y. Song, S.C. Kong (2014). *Going beyond textbooks: a study on seamless science inquiry in an upper primary class.* Educational Media International 51(3), 226-236. https://doi.org/10.1080/09523987.2014.968450

A teacher who wants to introduce the IBL method to the range of his practices should choose the level of this method for specific classroom conditions and the purpose of the classes. It is not recommended to start working in IBL method from implementation of the whole cycle, unless the activity is an out-of-curriculum lesson, meant to strengthen the motivation and positive attitude of learners, and it is strongly embedded in learners' interest. In other cases the cycle should be implemented step by step with regard to learners' age and abilities, experience in IBL and particular scientific problems or issues.

In earlier grades and in classes that have never worked in this way before, it is justified to start work from the lowest (structured) level, and only after applying several cycles – move on to the second (guided) level. The highest level (open), already requires students to be very independent and used to inquiry procedures, so it is recommended for students already familiar with the method. However, it can be introduced from time to time between the implementations of the method at two first levels as a kind of interlude, stimulating the curiosity of students and their research commitment, provided that the students are mature enough to choose the inquiry topic of their own interest. Undoubtedly, it is at the open level that the creativity of students is used to the fullest extent, which by repeatedly participating in the full cycle of work by IBL, it is also most fully developed. These types of activities, however, are not usually part of the curriculum content. It should be emphasized that research conducted on the effectiveness of the IBL method shows that the best educational results are obtained when using it at the first two levels[14].

Structured level is for the beginners
Guided level is the most effective
Open level is the most creative

[14] P.A. Kirschner, J. Sweller, R.E. Clark (2006). *Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching, Educational Psychologist"* 41(2), 75-86; A.W. Lazonder, R. Harmsen (2016), *Meta-Analysis of Inquiry Based Learning: Effects of Guidance,* Review of Educational Research, 86(3), 681-718; E.M. Furtak, T. Seidel, H. Iverson, D.C. Briggs (2012).

CHAPTER 2:
IBL - aspects of implementation

2.1 SETTING UP IBL IMPLEMENTATION

Before proceeding with the implementation of the IBL method, it is necessary to organize time and arrange the educational space, as well as to ensure appropriate mechanisms of student management, so that external conditions do not constitute an additional burden for the teacher and students working with this method.

2.2 WHEN TO START IBL IN SCHOOL?

The sooner, the better

A student starting their education at the first stage of education is as geared towards discovering and acting as they are at no other time in their development, which is why they become the best candidate to start working with the method of discovery through inquiry. Examples from the literature show that this method can be successfully used from the first grades of school education, although at first glance it gives the impression of a very demanding method in terms of practicalities, as well as time and group management. Numerous contemporary studies[15] prove that its use in younger classes is becoming not only a factor increasing the activity and motivation of students, but also a way to achieve much better results in deepening knowledge itself compared to more traditional teaching methods. And this is one of the most important factors shaping the activities undertaken by teachers in teaching at school.

2.3 GROUPING

The ideal would be to work with groups of a dozen or so, which in most classes would mean a division into two separate sub-classes, but this is not a necessary condition, and working with this method with groups of about 25 people is also possible for a teacher experienced in IBL. It is always a matter of the teacher's abilities of organization and class management. Teachers can find out by themselves the best way for effective allocation of groups, selection of group structure and number of group members, spatial arrangement etc., to make them most supportive for efficient learning. Such attempts have already been made by PLCTs in the course of the 3DIPhE project.

2.4 TIMETABLE

combined, consecutive lesson hours

Much more important seems to be the condition of combining two or even three consecutive lesson hours of a given subject in order to provide the teacher and students with comfort of work without excessive tension. The work of a researcher requires reflection, and experiments cannot be carried out in a hurry, both due to the effectiveness of the process of building inquiry competences and for the safety of students. The

Experimental and Quasi-Experimental Studies of Inquiry-Based Science Teaching: A Meta-Analysis, Review of Educational Research, 82(3), 300-329.

[15] D. Sokołowska, *Effectiveness of learning through guided inquiry, w: The Role of Laboratory Work in Improving Physics Teaching and Learning,* D. Sokołowska, M. Michelini (eds), 243-255; T. Bredderman (1983), *Effects of Activity-Based Elementary Science on Student Outcomes: A Quantitative Synthesis*, Review of Educational Research, 53(1), 499-518; G.N. Cervetti, J. Barber, R. Dorph, D.P. Pearson, P.G. Goldschmidt (2012). *The Impact of an Integrated Approach to Science and Literacy in Elementary Classrooms*, Journal of Research in Science Teaching, 49(5), 631-658

traditional division of school classes into subject classes, mainly single-subject, is forced at school on the basis of arguments that students are unable to focus on one topic for more than 45 minutes and the possibility of problems arising in the implementation of the program of the subject when one particular day of the week would be during the school year exposed to frequent cancellations for reasons such as celebrations, public holidays or class participation in activities outside of school (going to the cinema, theater, etc.). The first argument is easy to refute if you have ever participated in IBL science classes. Our many years of experience and observation of classes across Europe show that even students at the first stage of education are able to focus on classes conducted using this method for 60-90 minutes, due to the fact that they are constantly involved in such lessons, and the dynamics of the variability of their activities sustains the interest and thus the concentration of students. Students are often surprised that the lesson has already passed.

And the profit is not to be overestimated. Interviews with Polish teachers of the SAILS (Strategies for Assessment of Inquiry Learning in Science) project show that when organizing classes in the form of single lessons, teachers lose 10-20 minutes during each lesson on this type of activity. The result of such a school timetable format is a huge loss of time of student's presence in school, the inability to maintain his full concentration, and thus - the full use of his potential, interrupting unfinished work and shifting it to the time of homework. In such conditions, chaos and frustration arise, there is no room for developing student interests, skills, building motivation and commitment, and the time provided at school only allows for quick transfer of hard knowledge while ignoring the other two aspects of developing student competences. In this way, the school contributes to the creation of a reproductive society. Building a creative and reflective society requires the use of active methods, including the method of IBL, but with guaranteed conditions for their comfortable implementation, and not only taking into account their lofty goals and assumptions in the core curriculum.

Building a creative and reflective society requires the use of active methods.

2.5 CLASSROOM SPATIAL ARRANGEMENT

Another boundary condition for the effective implementation of the IBL method, which is extremely important when it is used in school practice, is the organization of space that should promote teacher's access to all groups of students and student comfort when conducting group experiments. It is suggested to provide a (a) horseshoe (b) nest/island setting for the classroom desks (Fig. 3).

(a) (b)

Fig. 3 Spatial arrangement, conducive to students' work in the IBL method. (a) a horseshoe (U-shape) setting in which half of the desks can be easily and quickly rearranged for work in the nest setting , (b) nest/island setting; students are symbolized by blue squares, and the teacher - a red square, equipment - desks and a blackboard - are displayed as rectangles

2.6 EQUIPMENT AND RESOURCES

The last element necessary to implement the IBL method in school is the equipment and materials. Many teachers complain about the lack of a proper science laboratory in their schools, some justify the lack of introducing experimental classes to their teaching practice. Although a well-equipped laboratory can be a source of inspiration and motivation for teachers to teach using experimental demonstrations and organization of laboratory work of students, it is not necessary to conduct such classes. Most biology, chemistry, physics and nature lesson modules based on experiments (especially in primary schools) can be implemented using everyday objects and several standard instruments and devices such as thermometers, microscopes, cylinders or measuring beakers, small sets of chemical reagents as well as digital meters and magnets. In particular the IBL method, largely referring to the life context, encourages experimentation with the use of items that every student can bring from home or which can be purchased at a very low cost. In this way, the student engages in the work cycle with this method even before starting the classroom, becoming - like a real researcher - responsible for the materials, tools and devices, with the help of which s/he then builds his inquiry competence. It is worth mentioning that a source of inspiration for the creative search for substitutes for expensive laboratory equipment, equally well (or maybe even better) for teaching science and natural sciences, can be for various teacher websites.

context learning,
everyday materials
on-line resources

2.7 IBL TAKES TIME

Teaching by IBL requires time. First, the teacher's time for solid content-wise and practical preparation for conducting classes using this method, as well as for the creation or adaptation of teaching materials. Secondly, provide sufficient time for the implementation of a single cycle, so that students can work without rush while passing between stages of the cycle (Fig. 1), have time to think and discuss in each group of these stages, as well as - to complete the tasks fairly belonging to individual parts of the cycle. Thirdly, because the method of inquiry is based on a process: its implementation itself becomes a process, so that implementation becomes effective in building natural competences (knowledge, skills and attitudes), it should be planned in time as a sequence of cycles. Fourthly, time is needed for an in-depth assessment of the effectiveness of the method - both in relation to student development (assessment of the implementation of a single cycle and aggregate assessment of the long-term competence growth process) and in relation to the teacher himself (e.g. through the teacher's self-assessment sheet).

time is a crucial
factor

Despite years of dissemination and promotion across the world, and in particular - across Europe[16], IBL is still not a common method of science education. Its implementation requires an evolutionary process - a practice of small but consistent steps taken at the level of: (1) central decision-makers (records in the core curriculum, training for teachers), (2) schools (permits of the management for the reorganization of space and time of classes, purchase of necessary materials), and above all - (3) individual practices used by the teachers themselves. Only in this way it will become possible to depart from the typically frontal and authoritarian teaching of science subjects, incompatible with the spirit of the scientific disciplines they represent, in favor of learning through experience, research and inquiry - typical activities in the fields of natural and exact sciences, i.e. biology, chemistry, physics and geography. Table 1 provides a summary of several practical tips for this evolution, presented earlier and derived from the recommendations of the Fibonacci project.

[16] Fibonacci Project, https://www.fondation-lamap.org/en/page/9546/fibonacci-a-european-project; Primas Project, https://primas-project.eu/, Establish Project, http://www.establish-fp7.eu/project.html, SAILS Project, http://www.sails-project.eu/, and others

… do more of this	… do less of this
Having students seated so that they can interact with each other in groups.	Having students seated in rows working individually.
Encouraging students to respect each others' views and feelings.	Allowing students to force their own ideas on others, not listening to others.
Asking open questions and ones that invite students to give their ideas.	Asking questions that call for nothing more than a one-word or short, factual response.
Finding out and taking account of students' prior experiences and ideas.	Ignoring students' ideas in favour of ensuring that they have the 'right' answer.
Helping students to develop and use inquiry skills of planning investigations, collecting evidence, analysing and interpreting evidence and reaching valid conclusions.	Giving students step-by-step instructions for any practical activity or reading about investigations that they could do for themselves.
Arranging for group and whole class discussion of ideas and outcomes of investigations.	Allowing students to respond and report individually only to the teacher.
Giving time for reflection and making reports in various ways appropriate to the type of investigation.	Giving students a set format in which to record what they did, found and concluded.
Providing feedback on oral and written reports that enables students to know how to improve their work.	Giving grades or marks and allowing students to judge themselves against each other in terms of marks or scores.
Providing students with a clear picture of the reason for particular tasks so that they can begin to take responsibility for their work.	Presenting activities without a rationale so that students encounter them as a set of unconnected exercises to be completed.
Using assessment formatively as an on-going part of teaching and ensure student progress in developing knowledge, understanding and skills.	Using assessment only to test what has been achieved at various times.

Table 1. Changing practice towards IBL[17].

[17] W. Harlen, (2012). *Inquiry in Science Education,* Fibonacci Project. Retrieved from https://www.fondation-lamap.org/sites/default/files/upload/media/minisites/action_internationale/inquiry_in_science_education.pdf

2.8 RESOLVING DOUBTS

CHAOS

One of the aspects, often indicated by the teachers themselves as the reason for failure in introducing this method of education in class, is the difficulty in maintaining discipline and order. Indeed, in the absence of developed time and group management mechanisms specific to this method, its implementation carries the risk of losing control over the educational process. It is at the first educational stage, when students are just starting their adventure with school, that there is a place to set the rules for dynamic variability of activities and mechanisms for silencing the class group during the lesson.

Chaos is manageable

We have not observed chaos syndromes or loss of teacher control over the lesson in any of the European schools visited by us using the IBL method. For example, at the Northbury Primary School in London, Essex, a nature lesson in a class of 7-8 year olds lasted 60 minutes. Students sat in groups of five throughout the lesson. During the teacher-moderated discussion, everyone was facing him, but while conducting the experiments, they sat facing each other in the same group. Thanks to the discipline held in the classroom, students very actively participated in teacher-moderated discussions and in peer group discussions, and also willingly shared all materials so that everyone could experiment. It should be emphasized, however, that disciplining students was part of the overall school strategy, upbringing in order and respect for others (but without introducing an atmosphere of fear), which was manifested by the constant use of a common method shared by all teachers to divide lesson time into short fragments with varying levels of activity , having their own rhythm, volume and fixed frames.

Younger students are action-oriented and are more likely to carry out trial and error experiments, and the requirement for strict prior planning of experience can slow them down and discourage them, thereby ruining the idea of discovery-exploring work. It is important that students have time to discuss ideas and then - to draw conclusions from their experiment. Group work culture is also very important. The IBL method gives great opportunities to practice communication between students, expressing their opinions, respecting the opinions and ideas of others, as well as honest assessment of the involvement of oneself and colleagues in the group's activities.

ONLY PLAYING

Quite often, both parents and teachers, formulate the opinion that the IBL method is just fun, for which there is no place in a limited time allocated to the implementation of a busy school program, and which does not contribute to the increase of students' knowledge. Nothing could be more wrong. Indeed, a part of the Inquiry-based learning is a growth of positive attitude (motivation, interest), originating from students' personal involvement. Since they involve emotions, having fun and playing are very important aspects of this engagement, supportive for the student education process on the whole, as it was proved by recent neurodidactics research.

Fun supports learning

Besides, if not the IBL method itself, at least the elements of this method have been introduced to the most of core curricula across EU countries over the last decade, and not only at the first stage of education, but also at all subsequent stages, especially in relation to science subjects. However parents and teachers may change their sceptic opinion about IBL only when the method is implemented commonly and on a regular basis, thus showing clearly its positive impact on the students' competences.

EFFECTIVENESS OF TEACHING AND LEARNING BY IBL

It would be an ideal situation if schools across the EU could ensure the widespread use of the IBL method in relation to natural competences from the first grade of primary school or even from kindergarten, when children entering the education system bring their willingness to act, show their own natural enthusiasm, openness and absorbency of anything around. At this stage, the method also gives great results in terms of learning effectiveness. Research conducted around the world shows that its effectiveness in acquiring knowledge also prevails at the subsequent stages of education, however it somehow decreases with age[18].

Just to show one example - research conducted in a group of 131 students aged 10-12 in Poland[19] showed a very low normalized change factor of a decrease of science content knowledge and inquiry skills in a medium term. The study compared students' scores just after the introduction of the IBL method in the form of a series of 10-h science lessons using a guided IBL in ten classes with their results obtained after a six-month period. The median of the normalized change factor in all groups was a total of -8.6%, which indicated the persistence of 91.4% of students' acquired knowledge and skills over a half-year period, which also included a two-month summer vacation. The normalized change factor did not differ statistically significantly between groups of girls and boys, nor between groups at different levels of skills, determined at the beginning of the study on the basis of the grades received by students at the end of the semester preceding implementation.

Medium-term retention exceeds 90%

So far, there is no consensus among researchers regarding the effectiveness of the IBL method by researching at further stages of education. This is due to, among others, definitely clearer differences in the educational experience of students (also in the application of this method at earlier educational stages) compared to younger students, as well as the boundary conditions of the research itself - carried out in different contexts and with regard to different levels of the method itself, often not explicitly specified in a given publication. One thing is certain - it is difficult to find any publication on the research on the application of this method in science education, which does not confirm its positive impact on the development of the affective sphere of students in relation to the science subjects in which it is used - i.e. increasing students' interest in the subject, increasing the attractiveness of themselves lessons, or a positive attitude to life sciences as such, regardless of the age of the students.

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[18] Y. Song, S.C. Kong (2014). Going beyond textbooks: *a study on seamless science inquiry in an upper primary class*, Educational Media International, 51(3), 226-236; J.E. Kukkonen, S. Kärkkäinen, P. Dillon, T. Keinonen (2014), T*he Effects of Scaffolded Simulation-Based Inquiry Learning on Fifth-Graders' Representations of the Greenhouse Effect,* International Journal of Science Education, 36(3) 406-424; R.W. Marx et al. (2004), *Inquiry-Based Science in the Middle Grades: Assessment of Learning in Urban Systemic Reform*, Journal of Research in Science Teaching, 41(10), 1063-1080.

[19] D. Sokołowska (2018), *Effectiveness of learning through guided inquiry, w: The Role of Laboratory Work in Improving Physics Teaching and Learning*, D. Sokołowska, M. Michelini (red), 243-255.

CHAPTER 3:
IBL Evaluation

Teaching by IBL, as a method of inductive learning, is in many studies compared and contrasted with the traditional, deductive teaching. It can be expected that also the effectiveness of these two extremely different teaching methods should be measured in completely different ways. Assessment in traditional teaching is dominated by tests based solely on knowledge and solving text problems, which in the IBL method is only one form of assessing the progress of students. Other very important ways to evaluate the teaching process are formative assessment, self- and peer-assessment, as well as the use of tests including practical tasks and scientific reasoning questions or concept questions. Only such a comprehensive approach to evaluation gives you the chance to reliably assess the process and change of the students' competences: their knowledge, skills and attitudes.

3.1 FORMATIVE ASSESSMENT

Formative assessment is the ongoing feedback given to a student by a teacher about the student's process of learning and the progress of his/her achievements in order to enhance student's motivation and monitor student's learning. The feedback can be one-to-one or group-based. In many formats it is based on the success criteria shared with the students. Formative assessment provides the teacher with adequate evidence about the effectiveness of his/her instruction, giving hints to the potential change of the teaching plan accordingly, still during the process of teaching. At the same time evidence about their understanding and achievements is revealed to the students in order to help them develop their learning styles and goals. In that sense formative assessment is perceived as *assessment for learning*[20]. Moreover formative assessment serves the purpose of moving the student's focus away from achieving grades towards the learning process, in order to develop their self-confidence, decrease their attitude of relying on extrinsic motivation and increase in students the sense of the ownership of their learning.

Although the formative assessment was introduced to education already in late sixties of the twentieth century, its idea was revised at the turn of the millenium and developed into a complete framework by Paul Black and Dylan Wiliam[21], stating that:

Practice in the classroom is formative to the extent that evidence about student achievement is elicited, interpreted and used by teachers, learners, or their peers, to make decisions about the next step in instruction[22] that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited.

They argue that the formative assessment demands from teachers to be constantly alerted and to be able to adapt their teaching plan and to outline the learners' goals according to the results of the interaction with students. The flexibility and individual or quasi-individual character of the formative assessment enables establishing different goals for different students or student groups, thus supporting differentiation in teaching and assessment. Students may even set up their own learning goals, in agreement with the teacher.

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[20] P. Black, C. Harrison, C. Lee, B. Marshall (2004). *Working inside the Black Box: Assessment for Learning in the Classroom,* Phi Delta Kappan, 86(1), 8-21

[21] P. Black, W. Dylan (2009). *Developing the theory of formative assessment*, Educational Assessment, Evaluation and Accountability, 21 (1), 5-31. https://doi.org/10.1007/s11092-008-9068-5

[22] "(...)the term "instruction" means the combination of teaching and learning (...) "instruction refers to any activity that is intended to create learning", ibid., pp. 9-10

Formative assessment comprises a range of formal and informal assessment technique[23], strategies[24] and tools. Some of the tools are described below.

CLASSROOM DIALOGUE

Formative assessment is to support the process of learning. One of the key aspects of this process is communication within and outside the learning group. Cognitive development requires constant transformation of student thoughts into well-formulated statements, understood by others, as well as the accurate verbal expression of statements and adoption of statements received from others. The success of the dialogue lies in critical thinking based on the respect towards other participants.

It was argued that *many teachers do not conduct classroom dialogue in ways that might help students to learn*[25]. And the key to changing this situation was sought in increasing time between posing a question and students' replies, preferably after allowing them brainstorming in small groups. Such an approach steers the questioning away from asking for facts and laws, towards conceptual questions, based on reasoning that can be easily revealed and elaborated during conversation.

Such instances of the classroom dialogue with different students can happen during the entire IBL cycle, while posing the inquiry question, hypothesizing, planning the investigation, conducting the experiments, data analysis and the phase of drawing conclusions. Feedback given by the teacher should be two-fold: asking questions that trigger the reasoning process and steer student minds towards understanding, and comments identifying what has been done well and what needs the improvement.

From such dialogues teachers benefit with a profound understanding of students' acquisition of concept knowledge and learn about their misconceptions. However such an approach demands from the teacher constant focus, non-stop following the students' ideas and formulation of adequate questions.

Dialogues give the teacher the opportunity for reflection that can be turned into the descriptive record of student achievements or notes in a reflective diary. One of the tools enabling collecting dialogue records in a fast way and with focus on particular issues is the activity chart.

ACTIVITY CHART

Activity chart is a tool that enables fast record of students' engagement during the brainstorming that usually starts the iBL cycle. It needs to be carefully designed and prepared in advance with focus on different aspects of student utterances.

An example of the activity chart used during the brainstorming is presented in Fig. 4. Prior to the activities the teacher chooses the aspects s/he wants to focus on and a group of students to assess during a brainstorming or dialogue. It is suggested that this should not exceed six students. During the brainstorming the teacher checks an appropriate box in the table to record the frequency and type of selected students' contributions. It is also possible to indicate cases where disrespect is shown to the peers' opinions expressed during the brainstorming,

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[23] K.M. Cauley, J.H. McMillan (2010). *Formative Assessment Techniques to Support Student Motivation and Achievement*, The Clearing House. **83**(1), 1–6. https://doi.org/10.1080/00098650903267784

[24] SAILS Project, http://www.sails-project.eu/

[25] P. Black, C. Harrison, C. Lee, B. Marshall (2004). *Working inside the Black Box: Assessment for Learning in the Classroom*, Phi Delta Kappan, 86(1), 8-21

e.g. by marking (R). In the example shown in Fig. 4, the teacher focuses on (1) the context quoted by students from everyday life or history, (2) use of scientific words by students and their meaning, (3) knowledge of scientific symbols. Teacher evaluates students' engagement in the brainstorming selecting criteria of (a) prior knowledge, (b) engagement and (c) creativity of a student. This way the quality of the dialogue can be monitored for the selected students.

Student name	Context - history, everyday life			Scientific words, meaning			Scientific symbols	
	Prior knowledge	Engagement	Creativity	Engagement	Prior knowledge	Creativity	Engagement	Prior knowledge
Name 1								
Name 2								
Name 3								

Fig. 4. Example of the activity chart used to record the information about the engagement of three students selected for formative assessment observation during the brainstorming in the classroom.

Activity charts, collected at different moments over the year, provide the teacher with the material helping him/her to understand a particular student level in developing specific skills and reasoning used in dialogues.

CONCEPT MAPS

A concept map (or a mind map) visualizes student knowledge in a structured way. It depicts ideas and concepts, and relationships among them in a brief, easy to catch graphical representation of key words, enriched by adequate pictorial elements and then connected by arrows showing the-above-mentioned relationships.

Concept maps were developed by Joseph D. Novak to enhance meaningful learning in sciences. They can be used both, as a way to increase meaningful learning, and to represent the knowledge already acquired and comprehended. The design of concept maps utilizes the full range of the left and right hemispheres of the brain, they aid in developing higher-level thinking skills and in recalling memory.

Among others a concept map can be used as a diagnosis for the prior-knowledge, a small task to activate students or trigger the group discussion, as a tool for drafting a project, launching the creative ideas, as well as a tool for study material repetition. It can be assigned to individuals, groups or to a whole class.

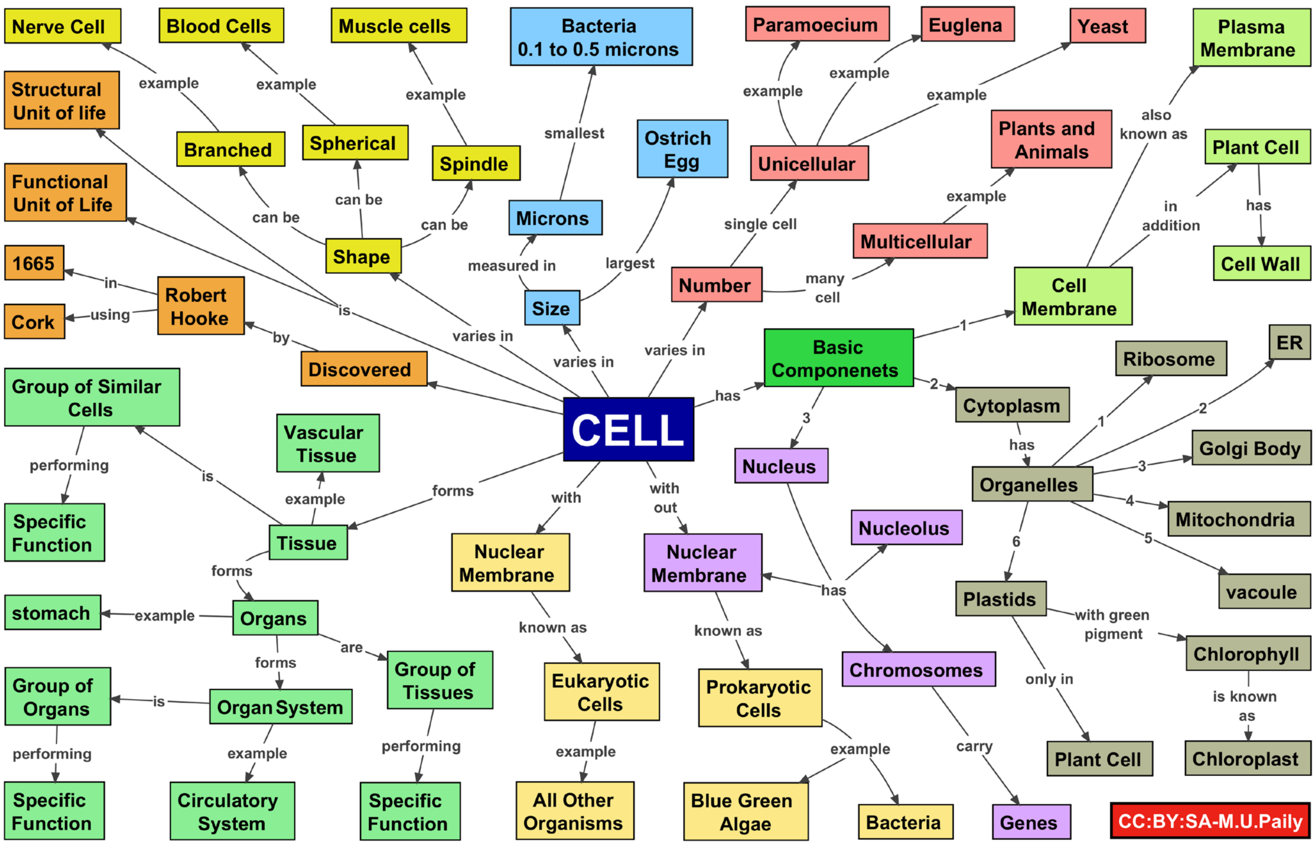

Fig. 5. An example of a Cell Concept Map (credit: M.U. Paily; source: Wikipedia; CC: BY-SA)

It is worth to note that many software tools helping in the design of concept maps are available, also as open sources.

Teachers can give feedback to the concept maps in dialogue with students or e.g. using the rubrics[26].

RUBRICS

IBL is one of the best methods to develop scientific abilities, understood as procedures, processes, and methods used by scientists when constructing knowledge and conducting experiments[27]. One way to assess their development is to use assessment rubrics. The rubrics are matrices containing specific scientific abilities, characterized at different levels of student performance. They can be also described as descriptive scoring schemes that are developed by teachers or other *evaluators to guide students' efforts*[28]. Depending on the scientific ability and student advancement, rubrics can be composed on 3-10 levels. There are two rules of a thumb for designing the rubrics:

- Each subsequent level assumes that the previous level's criteria have been met
- A clear, single criterion is used to distinguish two adjacent levels

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[26] see for example: http://www.sails-project.eu/sites/default/files/units/SAILS-unit_Electricity.pdf, pp. 32-33 & 36.

[27] E. Etkina et al. (2006). *Scientific abilities and their assessment,* PRE-ST 2, 020103; https://www.researchgate.net/publication/26495356_Scientific_abilities_and_their_assessment

[28] ibid.

The advancement from level to level can be quantitative (e.g. "student is able to provide one question" vs. "student is able to provide two or more questions"), qualitative (e.g. "student is able to formulate a question using only colloquial words" vs. "student is able to formulate a question using some scientific words") or based on the spectrum of linked abilities (e.g. "the student is able to draw a schema of a circuit enabling the flow of electric current" vs. "student is able to build a circuit enabling the flow of electric current"). In the same rubrics different types of distinction between levels may be used.

An example of rubrics for student's presentation of the data is shown in Fig. 6

Subability	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Is able to formulate an inquiry question verifiable in the classroom	is able to formulate a question which is not researchable	is able to formulate a question which is researchable, but not in given classroom circumstances	is able to provide one question verifiable in given classroom circumstances	is able to provide one question verifiable in given classroom circumstances, which s/he can investigate on the basis of his/her knowledge, past experience and inquire skills acquired so far	is able to provide more than one inquiry question, verifiable in given classroom circumstances and choose one that s/he will be able to investigate on the basis of his/her knowledge, past experience and inquire skills acquired so far	is able to provide more than one inquiry question, verifiable in given classroom circumstances and choose one that s/he will be able to investigate on the basis of his/her knowledge, past experience and inquire skills acquired so far; as well as s/he is able to anticipate on the same basis what result of the investigation is more probable

Fig. 6. A scoring rubric to evaluate the formulation of inquiry question (a rubric developed by PLCTI2 - experienced teachers in Poland)

Many other examples of rubrics for the assessment of lab work can be found for example in paper by Etkina et al.[29] and in classroom units developed in SAILS project[30].

Preparation of rubrics takes time, however, when using them, both the teacher and the student are clear about the level of development of a given student's skill or the degree of solving a given task by the student.

[29] E. Etkina et al. (2006). *Scientific abilities and their assessment,* PRE-ST 2, 020103; https://www.researchgate.net/publication/26495356_Scientific_abilities_and_their_assessment

[30] http://sails-project.eu/units.html

SELF- AND PEER-ASSESSMENT

Black et al.[31] argued t*hat students can achieve a learning goal only if they understand that goal and can assess what they need to do to reach it. So self-assessment is essential for learning.* Also peer-assessment can not be overestimated, because s*tudents may accept criticism of their work from one another they would not take seriously if the remarks were offered by a teacher.* Both self- and peer-assessment, when compared, are valuable for the teacher since they give an insight not only into the development of particular students' skills, but also to the relations between the group members and the development of a group as such.

Self- and peer evaluation are usually taken on the basis of the same set of questions formulated as statements describing various aspects of work in the group, the former - in relation to the student him/herself and the letter - with regard to other members of the group. So both set of statements are formulated analogously.

Below an example is shown on evaluation of the development of *working collaboratively*. Self-assessment tool allows the students to reflect on their involvement in group work during the lesson. Using the scale 0 (not at all) to 6 (very much), each student expresses his/her perception of his/her own engagement, according to the statements listed in the top table in Fig.7.

Self-assessment	0 (not at all)	1	2	3	4	5	6 (very much)
1. I was involved in planing the experiment							
2. I carried out the given tasks							
3. I helped colleagues							
4. I was involved in collection data							
5. I was active in performing the experiment							
6. I communicated properly with others							

Peer-assessment (scale:0-6)	Student A	Student B	Student C
1. Did your colleague take part in planing the experiment?			
2. Did your colleague take part in carrying out the given tasks?			
3. Did your colleague help the group?			
4. Did your colleague engage in data collection?			
5. Did your colleague take part in perfoprming the experiment?			
6. Did your colleague communicate properly in the group?			

Fig. 7 Exemplary self- (top) and peer-assessment (bottom) charts for evaluation of collaboration work in a group of four students during an inquiry investigation

[31] P. Black, C. Harrison, C. Lee, B. Marshall (2004). *Working inside the Black Box: Assessment for Learning in the Classroom,* Phi Delta Kappan, 86(1), 8-21

A similar peer-assessment tool is shown in the bottom table in Fig.7. It allows the student to reflect on the involvement of their peers in group work during the lesson. Using the scale 0 (not at all) to 6 (very much), students express their opinion about their peers' engagement, according to the statements listed.

More advanced students can contribute to this kind of assessment with their own criteria, discussed and agreed upon in the group or entire class. In such case self-assessment can be classified as *assessment as learning*[32].

3.2 SUMMATIVE ASSESSMENT TAILORED TO IBL

Summative tests are so embedded in the schooling system worldwide that a teacher cannot avoid using them even if working with IBL method. However summative tests can be tailored to the active learning methods with benefits for both, development of meaningful tests, based on scientific reasoning and scientific concepts and for changing the students' attitude (usually bad) to the summative assessment.

SUMMATIVE TESTS USED FOR FORMATIVE ASSESSMENT

It was argued by Black et al. that summative tests can be used for formative assessment two-fold. First when students prepare themselves for the end-of-a-unit test. For such an activity summative tests utilized in the past can be used to stimulate students to active revision of their knowledge and scientific reasoning, implemented in collaborative work. Students can also prepare their own assignments and challenge their peers with such tasks. It was proved that students trained to prepare for summative tests by generating and then answering their own questions outperformed other students who prepared in traditional, more passive ways[33].

INVESTIGATION TASKS

Particularly suitable for summative assessment of the development of inquiry skills during IBL lessons would be inclusion of tasks related to the inquiry process: posing an inquiry question, planning an investigation, putting forward hypotheses, choosing the right set of materials and devices accompanied by arguments justifying the particular choice, data analysis, drawing conclusions from given description of the experimental outcomes, etc. However as regarding the first four of the types mentioned above, it would be highly recommended to enable students solving the problem with use of real materials placed in front of them or even allowing to conduct a small investigation during the test. Such an approach reconstructs the IBL situation experienced in the classroom and more accurately reveals the level of development of particular inquiry skills and reasoning skills.

CONCEPT TASKS AND SCIENTIFIC REASONING TASKS

The nature of the Inquiry-Based Learning provides much more opportunities for development of scientific concepts and scientific reasoning skills in students than traditional methods, since instead of learning facts, rules and laws by heart, students challenge and verify their knowledge, their presumptions and misconceptions in the act of active investigation, incorporating their conceptual knowledge, investigative skills and social skills, as well as emotions. Such a holistic approach provides a good base for reinforcing higher-order thinking. So concept tests, like for example Force Concept Inventory[34] or reasoning tests, like Lawson test[35].

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[32] L.M. Earl (2014). *Assessment as Learning*, Hawker Brownlow Education https://files.hbe.com.au/samplepages/CO6941.pdf

[33] A.King (1992). F*acilitating Elaborative Learning Through Guided Student-Generated Questioning*, Educational Psychologist, 27, 111-126

[34] D. Hestenes, M. Wells, and G. Swackhamer (1992). *Force Concept Inventory,* Phys. Teach. 30, 141

[35] Lawson test revised in 2000, based on: A.E. Lawson (1978). *Development and validation of the classroom test of formal reasoning*. Journal of Research in Science Teaching, 15(1): 11-24. http://www.public.asu.edu/~anton1/AssessArticles/Assessments/Mathematics%20Assessments/Scientific%20Reasoning%20Test.pdf

3.3 TEACHER SELF-REFLECTION TOOL ON THE IBL PRACTICE

It is equally important that teachers develop their skills in evaluation of students working in IBL classes and at the same time teachers are able to evaluate the quality of their IBL lessons in the view of IBL principles. In order to help teachers in self-reflection on their IBL practice, a self-diagnostic tool was developed by the consortium of Fibonacci project and included in one of the Fibonacci booklets[36].

It is composed of a matrix with a list of specific, quite detailed questions about the IBL practice, concerning:

- sec.A. The teachers' Role - (1) building the students' ideas, (2) supporting students' own investigations, (3) guiding analysis and conclusions;
- sec. B. Students' Activities - (4) Carrying out investigations, (5) Working with others,
- sec. C. Students' Records - (6) Records students make of their work, (7) Students' written records

Teachers are encouraged to use the tool from time to time in order to monitor their own development of IBL teaching skills and the process of IBL that happens in their classrooms.

3.4 PRACTITIONER INQUIRY IN IBL

Inquiry-based Learning is an active method in which students learn by investigating and experiencing the scientific world of rules and laws in order to understand them, as well as to develop practical and social skills. A teacher who wants to deeper understand the learning process in his/her classroom, relations between students and all kinds of influences and interdependencies, may want to implement his own investigation, so called Practitioner Inquiry (PI).

The Practitioner Inquiry has got a lot in common with Inquiry-Based Learning. In particular both methods are founded on the analogous cycles of inquiry, which repeated frequently, lead to better understanding of the processes under interest. Intertwined as Practitioner Inquiry on IBL implementation in the classroom, both methods give a profound, genuine experience for teachers and students, challenging their current knowledge, opinions and skills, and as a result, enhancing and reinforcing their learning about inquired aspects at various levels.

In part 2 a full spectrum of IBL examples used by teachers participating in the 3DIPhE project is provided together with their reflections on the PI implemented in their own classes during the IBL lessons.

Volume 2 of this ebook provides insights into the Practitioner Inquiry method, as such.

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[36] Tools for Enhancing Inquiry in Science Education, S.B. Carulla (ed.), pp. 40-43 https://www.fondation-lamap.org/sites/default/files/upload/media/minisites/action_internationale/1-tools_for_enhancing_inquiry_in_science_education.pdf

SUMMARY

In recent years, there has been a general trend in the promotion of teaching that engages and increasingly links all three spheres of human development: cognitive, affective and psychomotor. Broad coverage recommendation documents and catchy slogans are created on this topic, such as 3H teaching / learning, where 3H is short for head, hand, heart and means education based on knowledge, skills and commitment shaping attitudes. Compared to traditional teaching, this means a more holistic approach to the student and to learning methods. In assumptions, we depart from traditional teaching, in which only the teacher plays an active role, and students are passive recipients of education (teacher-centered learning) - in favor of teaching, in which the student plays the main, active role, and the teacher plays the role of an advisor and supporting person (student-centered learning). Class observations and research results in the developing field of neurodidactics support these trends with regard to their purposefulness and effectiveness, and thus contribute to the foundations of new, 21st-century education. The question arises: to what extent do recommendations, scientific research in the field of teaching and records in official documents, such as the core curriculum, affect the actual shape of education in our schools?

The IBL method fits perfectly into these trends, is a tool for developing key students' skills, protects their knowledge and shapes inquiry attitudes, helps in developing communication skills and cooperation in a group, strengthens faith in one's abilities while maintaining respect for the achievements of others. As described so far in this publication and as it will be shown in the empirical part - it is relatively simple to introduce in nature lessons due to its flexibility and variety of applications, but requires teacher involvement, changing his thinking about education and redefining the role that the teacher plays in the process of educating students.

Work by the IBL method involves students through action, which is one of the main motivators of science and factors that increase its effectiveness[37]. The work cycle in this method, in a way mimicking the way scientists work in the natural and exact fields, gives students a unique opportunity to assimilate content through their own discovery and development of inquiry skills matching this content. Students learn the rules of scientific inquiry, learn to recognize variables in an experiment, control them, conduct reliable tests, and then draw conclusions based on objective experimental data. They learn that intuition sometimes lets the researcher down, and only a properly designed and conducted experiment can provide reliable and conclusive arguments. Learning through inquiry strengthens also the development of critical thinking, scientific argumentation, creativity and social competences, such as group collaboration, respect for others, and communication and presentation skills. At the same time, it ensures the acquisition of basic knowledge, which is especially important in the face of the necessity of taking students to external exams. What's more - it was shown[38] that the level of knowledge acquired in science lessons, conducted with use of the IBL method, only slightly decreased over a span of 6 months after implementation, and the decrease was independent of the gender and level of students. Numerous studies[39] also point to the fact that the IBL method gives a chance to obtain better results to students who perform poorly in traditional content-knowledge-based teaching. For all these reasons, teaching through inquiry is currently the widely recommended method of teaching science and science, but unfortunately it is still treated with enormous reserve in most schools across Europe.

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[37] S. Freeman et al. (2014)., *Active learning increases student performance in science, engineering, and mathematics,* Proceedings for the National Academy of Sciences of the United States of America, 111, 8410-8415; SECURE Recommendations, (2013), *Balancing the need between training for future scientists and broader societal needs. Recommendations for MST curricula in Europe*, p. 8 [online], http://a.nologo.website/secure/EN.pdf

[38] D. Sokołowska (2018), *Effectiveness of learning through guided inquiry, w: The Role of Laboratory Work in Improving Physics Teaching and Learning* (red. D. Sokołowska, M. Michelini), Springer, 243-255.

[39] M. Kogan, S.L. Laursen (2014). *Assessing Long-Term Effects of Inquiry-Based Learning: A Case Study from College mathematics,* Innovation in Higher Education, 39, 183-199; R.W. Marx et al. (2004), I*nquiry-Based Science in the Middle Graders: Assessment of Learning in Urban Systemic Reform,* Journal of Research in Science teaching, 41(10), 1063-1080.

PART B: EXAMPLES OF THE BEST IBL PRACTICES

In this part of the e-book we provide examples of the best IBL practices collected in two sets.
In Chapter 1 the best practices provided by coaches during the workshops on IBL with members of PLCTs are presented.
In Chapter 2 a collection of the best practices selected from the IBL units implemented by PLCT members in their classes is provided.

CHAPTER 1: Best IBL Practices by Coaches

CHAPTER 2: Best IBL Practices by Teachers

CHAPTER 1:
Best IBL Practices by Coaches

1.1 INTRODUCTION

Inquiry Based Learning, as an active method, demands from a teacher, who designs the learning, a specific preparation and an active approach. Despite years of the IBL dissemination and implementation across Europe, it is still quite common that teachers attending CPD workshops admit they have never heard about the method and thus they have never tried to implement it in their classrooms. Similarly, many of the teachers - members of PLCTs in the 3DIPhE project, were not familiar with the IBL and needed some initial introduction to the idea of the IBL method, its structure and examples of the IBL instruction.

During the PLCT meetings coaches organized sessions on IBL with use of the original, ready-to-use IBL units from a variety of resources, mostly EU projects[1] or materials adapted from other resource repositories[2]. Coaches designed also a set of units for the purpose of the 3DIPhE project. This collection is described in detail in the next chapter with the links to the materials for teachers (worksheets, presentations) gathered in the Appendix 1.

1.2 COLLECTION OF THE BEST IBL PRACTICES IMPLEMENTED BY COACHES

Below a list of ten best IBL examples and one generic template for the IBL unit is presented. The examples were introduced to the members of PLCTs during workshops provided by the 3DIPhE coaches during the course of the 3DIPhE project in four partner countries: Belgium (BE), Ireland (IE), Poland (PL) and Slovenia (SI), see Table 1.1.

The generic template can serve other coaches or teachers as a tool to effectively design their own IBL units. This template is very detailed and general, thus can be used for any IBL unit prepared at any IBL level. It is accompanied by general templates (a student worksheet, a poster and a guide for teachers) ready to be adapted to the specific topic and purpose.

Ten other examples are ready-to-use blocks of materials, each comprising: a general characteristics of the unit and the description of the course of its implementation, a worksheet for students, a guide for the teacher and, in some cases, presentations that can be used in the classroom.

[1] ESTABLISH Project http://www.establish-fp7.eu/resources/units.html; SAILS Project, http://www.sails-project.eu/units.html

[2] SCIENTIX, http://www.scientix.eu/resources; EXPLORATORIUM, https://www.exploratorium.edu/education/teaching-resources; Firefly Project https://www.swietlik.edu.pl/jak-sie-przygotowac/doswiadczenia (in Polish)

No.	IBL modul title	Author(s)	Country
1.	Double shadow	Mojca Čepič, Maja Pečar and Ana Gostinčar Blagotinšek	SI
2.	Friction	Dagmara Sokołowska	PL
3.	Penumbra and the spreading shadow	Mojca Čepič, Maja Pečar and Ana Gostinčar Blagotinšek	SI
4.	Plasma Spheres	Jan de Lange	BE
5.	Pressure	Mojca Čepič and Ana Gostinčar Blagotinšek	SI
6.	Rainbow in a box	Dagmara Sokołowska	PL
7.	Spaghetti Bridge	Dagmara Sokołowska	PL
8.	Speed	Eilish McLoughlin	IE
9.	Subtle shifts	Jan de Lange	BE
10.	Which chocolate is the best	Ana Gostinčar Blagotinšek	SI
11.	Generic template for the IBl unit	Ana Gostinčar Blagotinšek, Maja Pečar and Mojca Čepič	SI

Table 1.1. The best IBL practices by 3DIPhE coaches

Each unit is firstly presented in a short description of the characteristics of the unit and the features of its potential implementation. A compact table informs about the IBL level and the most adequate age of students, as well as about the proposed student grouping strategy. Moreover, the key concepts of the unit are provided as indicators divided into three categories : (A) inquiry skills, (B) scientific reasoning and (C) scientific literacy developed during the unit implementation. Subsequently, a detailed description of the IBL unit and a model sequence of its use is given with additional hints for a teacher. Some units contain an extended description of the assessment methods incorporated in the unit, both formative and summative; in some others information about the assessment strategy is very brief or not included. In the Coach's Advice subsection some remarks and recommendations are given by the coach, who designed the unit. In addition, the coaches share their learnings from the implementation of the unit during the 3DIPhE workshops for PLCT. Each coach's example is accompanied by supplementary material: a worksheet for students, a guide for a teacher and/or a presentation, ready-to-use in the classroom.

The collection contains the units mostly related to topics from physics. Only two units relate to the topics that are considered in both physics and chemistry curricula. The units are designed at different IBL levels and in many cases some of the activities are related to a lower IBL level, some others to an upper IBL level. In half of the units the age of students is not mentioned, the other half of the units indicates age 15-19 with one exception of age 13-15. All units can be easily adapted for special activities with younger students (e.g. workshops) or can be upgraded for lessons with older students. Units are designed to be utilized in classes divided into groups of two, three or four students. The grouping procedure is left to the teacher's choice. Depending on the teacher's own interest the groups can be formed by random or with respect to the gender or students' abilities. Teachers can also divide students on purpose into mixed-gender and/or mixed-abilities groups. Table 1.3 gathers all this information for all coach's units, indicating also the forms of assessment proposed in units and the types of supplementary material accompanying each unit and available in the Appendix 1 (abbreviations used in Table 1.3 are explained in Table 1.2).

category	abbr.	explanation
IBL level	S	structured IBL
	G	guided IBL
	O	open IBL
Subject	Ph	physics
	Ch	chemistry
Age		
	CD	curriculum - dependent
	N/D	not defined; suitable for different ages
Curriculum	C	
	SC	standard curriculum (the same for all at this age)
	BC	basic curriculum
	AC	advanced curriculum
	N/D	not defined; suitable for different curricula
Assessment	A	
	FA	implementation of formative Assessment
	SA	implementation of summative assessment
Supplementary material available	SM	
	G	Guide for teachers
	W	Student worksheet
	PT	Poster template
	P	Presentation
	A	Additional material
	FA	Formative Assessment Tool
	L	a link to the original material is provided

Table 1.2. Abbreviations used in Table 1.3

No.	IBL module title	IBL level	Subject	Age	C	Students per group	A	SM
1.	Double shadow	O	Ph	N/D	AC	2-3	F&S	G&W
2.	Friction	S&G	Ph	15-19	BC	3-4	F&S	G&W
3.	Penumbra and the spreading shadow	G&O	Ph	N/D	-	2-4	F&S	G&W&A&L
4.	Plasma Spheres	O	Ph	15-19	-	2-3	F	P
5.	Pressure	S	Ph	13-15	SC	2-3	F&S	G&W
6.	Rainbow in a box	S&G	Ph	15-19	BC/AC	3-4	-	W&P&A
7.	Spaghetti Bridge	G&O	Ph	N/D	-	2-3	F	W&P
8.	Speed	G&O	Ph	N/D	SC/BC	3	F&S	G&W&FA
9.	Subtle shifts	S&G	Ph/Ch	15-19	-	2	-	W&A&L
10.	Which chocolate is the best	S	Ph/Ch	N/D	N/D	3-4	-	G&W
11.	Generic template for the IBL unit							G&W&PT&L

Table 1.3. Summary of general information about the best practices developed by coaches for PLCT workshops during the 3DIPhE project (abbreviations explained in Table 1.2)

On the basis of the short descriptions of the coaches' IBL units, three separate lists of indicators related to three categories: (A) IBL skills, (B) scientific reasoning skills and (C) scientific literacy aspects were identified as addressed by coaches in their IBL implementations (see Table 1.4). The lists differ a bit from the relevant lists of indicators identified by teachers in their IBL examples (compare Table 2.4).

ID	IBL skills	ID	Scientific reasoning skills	ID	Scientific literacy acquirements
A1	generating ideas in discussion	B1	identification of variables	C1	reviewing prior knowledge
A2	elaborating research questions	B2	classifications	C2	understanding the properties of physical/ chemical/biological quantities
A3	developing hypotheses	B3	making scientific connections	C3	evaluate and design scientific investigation
A4	planning investigation	B4	proportional and/or inversely proportional reasoning	C4	presentation of scientific data (graphs, tables)
A5	design testing experiments	B5	application of acquired knowledge in a new situation	C5	scientific explanation of concepts (use of scientific expressions)
A6	forming coherent arguments	B6	choosing right components (materials, devices)	C6	evaluation of the content (e.g. food, substances)
A7	working collaboratively	B7	problem solving	C7	searching for information in external sources
A8	data gathering skills	B8	making comparisons	C8	scientific explanation of phenomena
A9	data analysis skills	B9	identification of reasons	C9	understanding physical quantities
A10	drawing conclusions			C10	understanding the real world context of the topic
A11	presentation of the results			C11	fair test
				C12	relevance for everyday life

Table 1.4. The list of inquiry skills, scientific reasoning skills and scientific literacy aspects incorporated into the best IBL examples provided by coaches.

Below, Tables 1.5, 1.6 and 1.7 present separately three lists of categories from Table 1.4. In these tables individual indicators are assigned to individual units in which they are addressed.

Table 1.5 gives an overview onto the IBL skills identified by coaches as skills that can be developed during the implementation of their units. In most of the units the development of five or seven IBL skills is addressed during the implementation; however the span is broad and ranges from three to ten IBL skills.

No.	IBL modul title	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
1.	Double shadow			✓	✓	✓	✓	✓			✓	✓
2.	Friction	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
3.	Penumbra and the spreading shadow		✓	✓	✓		✓	✓			✓	✓
4.	Plasma Spheres	✓									✓	✓
5.	Pressure			✓	✓	✓		✓			✓	✓
6.	Rainbow in a box	✓		✓			✓	✓	✓		✓	✓
7.	Spaghetti Bridge	✓			✓			✓				✓
8.	Speed				✓			✓	✓	✓	✓	
9.	Subtle shifts			✓	✓		✓		✓		✓	
10.	Which chocolate is the best		✓	✓	✓	✓		✓			✓	✓

Table 1.5. IBL skills identified by coaches as skills developed during the implementation of the best IBL examples designed by coaches.

The skill of drawing conclusions is reported by coaches in nine out of ten cases. Most of the units include the activity of planning investigation, developing hypotheses and presentation of the results. Equally often development of the collaborative working skills is mentioned by coaches. In half of the units one may expect that students are asked to form coherent arguments. In four cases the coaches put emphasis on the initial generation of ideas in the discussion in the class. Exactly the same number of units incorporates the design of testing experiments and development of data gathering skills. Elaboration of the research questions by students is mentioned only in two examples, similarly to data analysis skills.

Tha coaches identified also nine scientific reasoning skills in their best examples of the IBL units, as indicated in Table 1.6. Development of the skill of identification of variables and the skill of making comparison are mentioned in almost all units. In a bit more than a half of examples students practice the skill of making scientific connections with real situations. Much less frequently the units require application of acquired knowledge in a new situation and identification of reasons. In the examples provided by coaches, the skill of taking decisions on the choice of the right components to conduct experiments are least popular, similarly to classifying the objects, proportional or inversely proportional reasoning and problem solving.

No.	IBL modul title	B1	B2	B3	B4	B5	B6	B7	B8	B9
1.	Alcoholic Fermentation	✓		✓					✓	✓
2.	Balance of forces and use of trigonometric functions	✓		✓	✓		✓		✓	
3.	Density	✓		✓					✓	✓
4.	Determining Taste Zones of the Tongue		✓							
5.	Earth and Space	✓		✓		✓			✓	✓
6.	Eco-Travelling			✓			✓		✓	
7.	Electrical circuits					✓		✓		
8.	Electricity	✓							✓	
9.	Exploring the Perimeter and the Area of Complex Objects	✓							✓	
10.	Gravitation, Weight & Centrifugal Force	✓		✓		✓			✓	

Table 1.6. Scientific reasoning skills identified by coaches as skills developed during the implementation of the best IBL examples designed by coaches.

As many as twelve items were identified by coaches as indicators for scientific literacy acquisitions, incorporated in the coaches' IBL units. The most often addressed are the acquisitions of evaluation and design of scientific investigations, scientific explanation of concepts (with use of scientific expressions) and understanding the real world context of the topic. In half of the units the coaches anticipated scientific explanation of phenomena by students. Three out of ten coaches' IBL examples mention reviewing prior knowledge, presentation of scientific data with use of graphs or tables, as well as the goal of understanding physical quantities. Each of the other scientific literacy items is addressed only in one or two units. The details are provided in Table 1.7

No.	IBL modul title	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1.	Double shadow			✓	✓	✓			✓				
2.	Friction	✓	✓	✓		✓			✓	✓	✓	✓	
3.	Penumbra and the spreading shadow			✓	✓	✓			✓				✓
4.	Plasma Spheres										✓		
5.	Pressure			✓		✓							
6.	Rainbow in a box	✓	✓			✓		✓	✓	✓	✓		
7.	Spaghetti Bridge	✓									✓		
8.	Speed			✓	✓	✓			✓	✓	✓		
9.	Subtle shifts			✓									
10.	Which chocolate is the best			✓		✓	✓				✓	✓	

Table 1.7. Scientific literacy aspects identified by coaches as skills developed during the implementation of the best IBL examples designed by coaches.

In summary, the collection of the best IBL examples provided by coaches comprises ten IBL units ready-to-use in physics classes with groups of students from lower and upper secondary school. The units are complete with regard to the topics, purposes and the use of the IBL method, however they can be adapted by teachers or other coaches giving the IBL workshops in order to serve better the purposes of specific curricula or topics. All coaches' units are accompanied by the supplementary material, like students' worksheets, teacher guides and/or original presentations. The supporting materials are provided in both pdfs and editable documents, the latter in order to enable the users its easy modification.

The collection comprises a broad spectrum of topics, from basic issues, common for most curricula (Friction, Pressure, Speed) to more advanced (Double Shadow, Penumbra, Subtle Shifts) or even out-of-standard-curricula examples (Plasma Spheres, Which chocolate is the best). Details of the course of implementation lead the reader through each unit with focus on the topic and the IBL method. Descriptions provide also the reasoning behind the implementation in terms of the IBL skills anticipated to be developed in students, scientific reasoning skills and scientific literacy acquisitions incorporated into the design of the unit. Assessment insets, both formative and summative, complete the strategy of the IBL implementation. The Coach's Advice subsections provide remarks and recommendations based on the coaches' own experience. Last but not least, each unit contains the coach's learnings from the implementation in the 3DIPhE workshops for PLCTs. All that makes the set of the best examples by coaches, provided in the subsequent section, a collection of authentic material, well thought over and practiced in both, classes and in workshops for teachers, thus taking into account specificity of each of these two implementations.

1.3 THE BEST IBL PRACTICES BY COACHES

1.3.1

Double shadow

Mojca Čepič, Maja Pečar and Ana Gostinčar Blagotinšek, SI

The unit was developed by Mojca Čepič, Maja Pečar and Ana Gostinčar Blagotinšek, from University of Ljubljana, Faculty of Education, Slovenia.

Context and goals

Double shadow occurs when an object is placed on a reflective surface and is illuminated by a parallel light beam from a torch or the sunlight. If direction of light is such that the reflection results in a large bright spot on the wall or the screen (see Fig.1 a), the object on the surface (Fig.1b) casts two shadows (Fig.1 c), which have mirror symmetry one with respect to another.

(a) (b) (c)

Figure 1. (a) An observation of the phenomenon is possible at home, as in presented circumstances.
(b) Partial reflection on a glass surface of the table acts like a mirror. (c) Both objects cast a double shadow within the light spot.

Although shadows are well-known everyday phenomena, this specific observation is known to meticulous observers only. It occurs rather rarely, but it is very easy to intentionally create circumstances for its observation and inquiry.

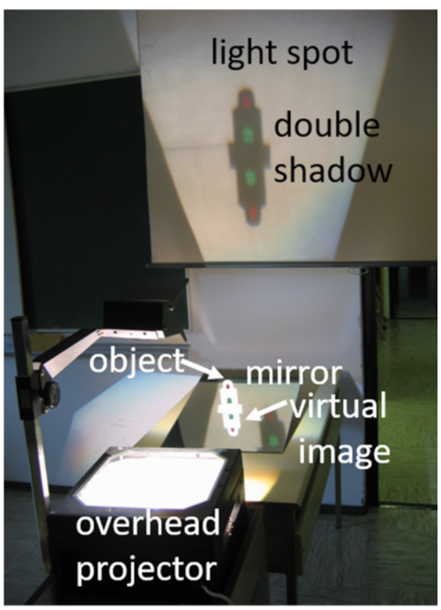
GOAL	• to train/improve the observation skills • to encourage predictions • to design testing experiments • to accompany students' reasoning by sketches/drawings • to draw conclusions • to learn something new from everyday life
IBL LEVEL	Open inquiry
AGE & SCHOOL TYPE	Appropriate for all levels when students already know the law of reflection and are able to apply it in different circumstances. The knowledge of ray diagrams is also helpful.
GROUPING	• 2 – 3 students • randomly formed groups with respect to ability, gender and friendship by drawing cards; • desks for two persons or two individual desks together
IBL unit resources	Mojca Čepič (2006), Do virtual images cast shadows?, Phys. Ed. Vol. 41, No 4, 295-297.
Key concepts	reflection of light, shadow

Inquiry skills developed	• planning investigation • working collaboratively • drawing conclusions • presentation of the results • articulating predictions • forming coherent arguments • designing testing experiments
Scientific reasoning	• identification of variables • making scientific connections • making comparisons • identification of reasons
Scientific literacy	• evaluate and design scientific investigation • presentation of scientific data (sketches, drawings of ray diagrams) • scientific explanation of concepts (use of scientific expressions) • scientific explanation of phenomena

Unit description

1. Introduction

The lesson is focused on two aspects: recreating and investigating circumstances that allow for observation of the phenomenon presented in Fig. 1, and to inquire the reasons for the appearance of a double shadow. As an existing experience of students is unlikely, the teacher demonstrates the phenomenon (Fig. 2) at the beginning of the lesson.



The best demonstration is carried out with an overhead projector as a parallel light source, a big mirror (approximately 40 times 60 cm), a whiteboard in a function of a screen, and a small, flat asymmetric object. The object in Fig. 2 has two holes covered with transparent foils of two different colours to track the light beams easier, but it is not compulsory. If an overhead projector is not available, a torch, like a big Maglite with a relatively wide parallel beam is appropriate. In this case it is advisable that the screen is set perpendicularly to the mirror in contact with it to prevent extensive penumbras.

Figure 2. The big setup for demonstration of the phenomenon. All the important issues are clearly seen and invite students to recreate them in smaller setups, which allow the observation.

2. Students introductory activity

The students first recreate the circumstances that allow observation of double shadows using an equipment provided by the teacher. Next, they investigate the phenomenon for a while to gain experience.

Equipment per group

- 1 mirror (around 10 cm times 20 cm or larger. The larger the better.)
- 1 or 2 flat objects without up down symmetry, but it is advisable that at least one object is not symmetric at all. If the choice is left to students, they often use erasers or pens that are too symmetrical for evident observation.
- A torch covered with translucent paper like paus. Direct light from the torch does not provide clear shadows due to focusing issues of parabolic mirrors in the background of torches. The mirror is illuminated from a distance between 0.5 m to 1 m.
- A screen on which shadows are observed. Simple 5 g A4 paper can be used with a support of a notebook or anything similar.
- A tape if anything has to be fixed, for example, a screen paper on the notebook.
- Scissors, not necessary, but students often try to shape their own objects.

The teacher stimulates investigations with questions if some participants do not "play" with the equipment in a sensible way, for example: Can you show me your double shadow? Which positions of the torch/screen/object result in the nicest double shadow?

3. Sketching and vocabulary

As this inquiry is rather open, it is important to encourage the articulation of observation. Besides talking, the teacher encourages her/his students to sketch the phenomenon, articulate their observations and fill in the worksheet.

4. Why does the double shadow occur?

There are two shadows on the screen and the most satisfactory answer presents the reasons for the appearance of each of them orally, with a sketch and with a demonstration of the testing experiment, which supports the reasoning. in some circumstance a direct shadow of the object also appears on the screen. To avoid this, the incident angle of light on the mirror should be between 30˚ and 60˚. However, if a direct shadow is observed, it is worth encouraging an inquiry of its origin.

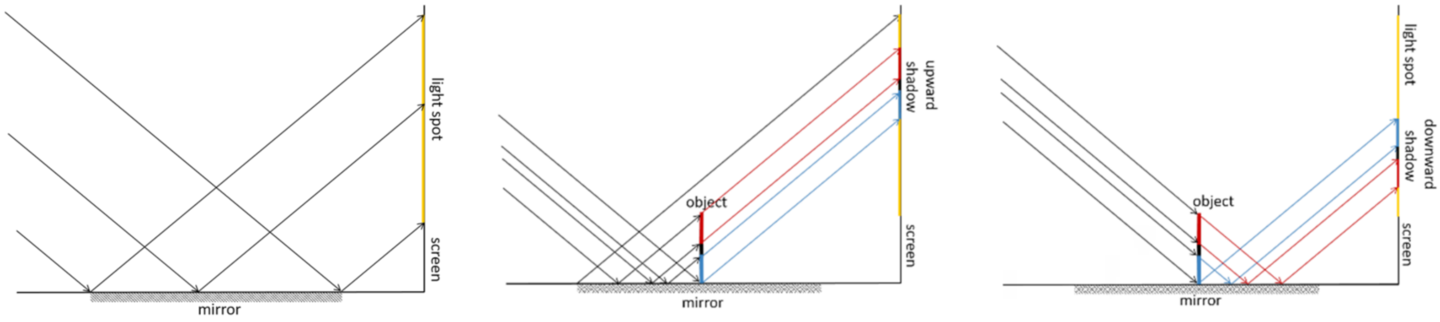
5. Expected explanations

The light spot on the wall without shadows occurs because the parallel beam of light falling on the mirror is reflected and illuminates an area on the screen (Fig 3a). Bright region can be determined in advance using the law of reflection. If students do not try to draw ray diagrams, the teacher encourages them suggesting drawing the ray diagram without an object.

Two shadows within the light spot occur because of the following reasons

- A part of the light beam reflects on the mirror first and is absorbed by the object after the reflection. This absorption results in the upward shadow.
- A part of the beam illuminates the object and is absorbed and specularly reflected from it in all directions. A reflection of light from the mirror behind the object is missing and results in a downward shadow.

An ideal predicted and by reasoning supported explanation is presented by ray diagrams, similar to Fig. 3. However, students usually play with the setup, move an object around the mirror and when the object is near the edge toward the screen or closer to the light, one of the shadows disappears. This recognition often stimulates planned inquiry and only after enough experiences they articulate the reasons either by drawing or in words. At this point, students are encouraged to add the missing part, either to write an explanation or the ray diagram or put both in the proper frame in the worksheet. In addition, they are asked to demonstrate by an experiment, that is, to design a testing experiment for their explanation.



(a) (b) (c)

Figure 3. (a) Ray diagram for the light spot. (b) Ray diagram for the upward oriented shadow within the light spot. (c) Ray diagram for the downward oriented shadow within the light spot.

Drawing or in words. At this point, students are encouraged to add the missing part, either to write an explanation or the ray diagram or put both in the proper frame in the worksheet. In addition, they are asked to demonstrate by an experiment, that is, to design a testing experiment for their explanation.

6. Testing experiment, prediction of outcomes and their meaning

Two testing experiments are possible, and both prevent one of reflections, that is, in front or behind the object. One possibility was already mentioned, to place the object on the mirror close to its edge that one or another reflection is not possible. Another possibility is to cover the mirror in front or behind the object with a piece of paper that prevents reflection (Fig. 4).

(a) (b)

Figure 4. (a) Downward oriented shadow appears in the light reflected behind the object. (b) Upward oriented shadow appears in the light reflected in front of the mirror.

Students predict, which shadow disappears/remains and what does the observed result mean for their explanation, does it disprove it or not. The "confirmation" of the explanation should be avoided as it is not conclusive.

7. Conclusions

In the final part of the unit students report their observations, explanations, describe the testing experiments, and what the results of testing experiments mean for their explanation. The teacher helps with articulation of the new knowledge

- Even with a single light source objects can have more than one shadow.
- The shadow appears always, when the light is blocked and is not diffused.
- In the inquired case two oppositely oriented shadows exist, one oriented in the same direction as the object and one in the opposite direction.
- The shadow with the same orientation appears due to the light reflected from the mirror in front of the object.
- The shadow with the opposite orientation appears because the object casts the shadow to the mirror behind the object and consequently there is no light to reflect there.

Assessment methods incorporated into IBL

Formative: The activity is appropriate for students that are already familiar with ray diagrams and the law of reflection. Correct drawings demonstrate a student's comprehension of ray diagrams. The activity of drawing ray diagrams can be extended to mirror images of objects on the mirror and to comparison of observations. To help students focusing on the ray diagram, the sketch of the setup might be added, either to the working sheet (appendix A) or as a separate picture similar to the one below.

Summative: Ray diagrams of similar setups can be used for verification of ray diagrams in written tests. Our advice is to use a structured task starting with drawing shadows of objects on screens tilted in different directions (Fig. 5 a). As an additional task for students with higher abilities, the mirror is added below the object that can cast a "reflected" shadow to the "hill" (Fig. 5 b). For the second picture it is important that the obliqueness of the sunlight is larger than the slope of the hill, which acts as a screen. The teacher can place an additional screen anywhere, but for construction of both shadows it is advisable that the shadows do not appear in the air.

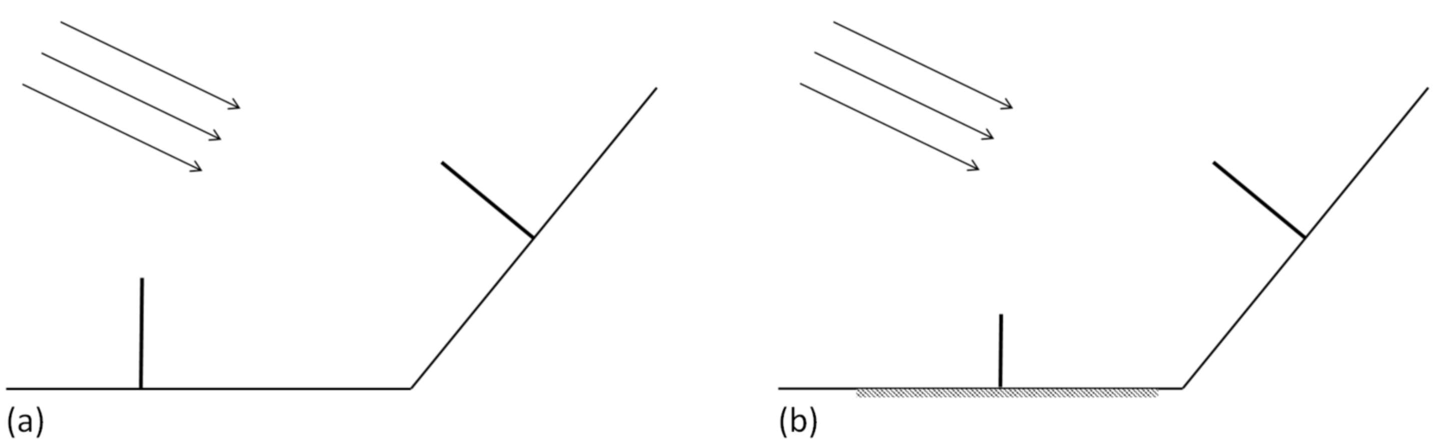


Figure 5. (a) A simple test picture that verifies if a student is able to use ray diagrams to predict shadows. (b) The test picture addresses the unit directly, but is not a simple reproduction due to the tilted screen.

Coach's Advice for implementation in the classroom

There are few problems the teacher might meet during implementation. First, students usually do not want to fill in worksheets, they prefer to "play". While having fun is nice, the teacher may want to use this unit for demonstrating the application of ray diagrams and the law of reflection, and to train scientific skills like planning, drawing conclusions and reporting. Therefore, the teacher has to check the students' notes. If students do not finish the unit with organized notes, it is highly likely that they will remember the activity vaguely and will completely forget the reasons for double shadows.

Ray diagrams, especially predictions of testing experiments are best drawn as side views in two dimensions. If students are left to themselves, they tend to draw in three dimensions, which is more difficult and the perspective does not allow to use the law of reflection clearly. Depending on students' level, the teacher can include a scheme for drawing from the worksheet for teacher (Appendix B) in the worksheet for students (Appendix A), draw the scheme to the white board, gives the scheme on a separate piece of paper to students or just instruct the students to sketch a side view in two dimensions.

Coach's Learnings from implementation during the 3DIPhE workshops

The activity was performed on three occasions, with both Slovenian professional learning communities in 2019 spring and fall and with two groups during the multiplier event in Dublin/Ireland in March 2020.

It turned out in all occasions that even adults/teachers prefer to play with the setup, try different scenarios etc. than keep notes, draw sketches, think about the reasons etc. Therefore, one could expect similar attitudes from students, which led to suggestions for the classroom implementation of the unit given above.

Supplementary material

The worksheet for students is found under name 3D_IBL Worksheet_Double shadow_UL.pdf,
and in its editable form 3D_IBL Worksheet_Double shadow_UL.docx.

The guide for a teacher is found under name 3D_IBL Guide_Double shadow_UL.pdf, and in its editable form, which allows for copying pictures, modifications and notes for later use is 3D_IBL Guide_Double shadow_UL.docx.

There is also a Inquiry Guide poster.

1.3.2

Friction

Dagmara Sokołowska, PL

The tool was developed by Dagmara Sokołowska from Jagiellonian University, Krakow, Poland, Faculty of Physics, Astronomy and Applied Computer Sciences.

Context and goals

Friction is experienced in our lives every day. It is very important that they realize different types of friction, advantages and disadvantages of friction presence in particular situations, as well as they understand factors influencing friction.

The tool helps the teacher, who is a beginner in the inquiry based learning, to effectively plan and carry out an IBL lesson. Worksheets for students encourage conscious planning and other actions needed in inquiry and systematic inquiry notes.

GOAL	Understanding friction in a context of everyday life, its advantages and disadvantages and the influence of different factors on friction.
IBL LEVEL	warming-up: STRUCTURED, main part: GUIDED
AGE & SCHOOL TYPE	• Adequate for introduction of the Friction topic in both, lower and upper secondary school (15-19). • Can be used also with younger students. However, in such a case some of the text in a worksheet for students could be left out or rearticulated with use of more simple expressions.
GROUPING	• preferably 4 students per group • it can be also done in pairs or trios if it is more appropriate for the given classroom situation • depending on the teacher additional interest, groups can be formed by random or with special focus on gender or student ability composition • groups can be formed by a teacher or students themselves
IBL unit resources	Coach's original material
Key concepts	• Static friction, kinetic friction, rolling friction • independent, dependent and control variables
Inquiry skills developed	• generating ideas in discussion • planning investigation, • developing hypothesis, • forming coherent arguments, • working collaboratively, • data gathering skills, • data analysis skills, • drawing conclusions • presentation of the results

Scientific reasoning	• identification of variables, • making scientific connections, • proportional reasoning, • choosing right components, • making comparisons
Scientific literacy	• reviewing prior knowledge • understanding the properties of physical quantities, • evaluate and design scientific investigation, • scientific explanation of concepts (use of scientific expressions) • scientific explanation of phenomena, • understanding of physical quantities, • understanding the real world context of the topic, • fair test

Description of a tool and its use

Below the implementation of the unit is described in details in a chronological order. Parts of the description related to the Guide for teachers are marked in blue.

The activity takes ca. 2 lesson hours, preferably in a row. During the entire implementation students take notes in their worksheets.

1. At the beginning of the first lesson the teacher organizes a brainstorming, in which students recall and **review** together their **prior knowledge** about friction and everyday examples linked to it. The first attempt to describe friction is made, it is very likely that also types of friction are named and distinguished. Also friction may be **related to the friction force (use of scientific expressions**) at this point. Examples of possible starting points or questions are provided in the Guide for teachers
2. Students are asked to write down examples of a few situations in which friction impedes human life, work etc. and a few situations in which friction supports human life, work etc. After individual reflection students **compare the examples in groups** , thus **deepening understanding of the real world context of the topic.**
3. The first IBL activity described in the worksheet, i.e. TWO BOOKS is structured and done in pairs. Students **reason** about the results of the experiment, and the first step of **understanding of the properties of friction** emerges from this experiment.
4. In the next step 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?
   There are two possibilities for the subsequent work:
   - Students discuss on a forum on the choice of possible factors influencing one, two or three types of friction, and the teacher together with students selects the factors to investigate (basic scenario).
   - Students start to work in individual groups on this question (advanced scenario)

   In what follows we describe the advanced scenario.
5. 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 **identification of variables** is completed.
6. Students link phenomenon and quantities to the measurement with the available equipment.
7. Students select types of friction and factors influencing 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.
8. While working in groups, students **formulate** a specified **inquiry question** (or a few questions).
9. Students **develop** their group **hypotheses**.

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

10. 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 right components**
    Which data will we collect? How will we record them?
    Teachers monitor 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 do investigation and collect evidence.
12. Initial **data analysis** takes place. If the results do not lead to the conclusions and answer 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 correctness (or inadequacy) of the hypotheses and their explanations, however he/she 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.

After completing the investigation the teacher may ask students about their suggestions on extension of this inquiry or inquiry on related topics for the further study.

15. Students come back to the experiment TWO BOOKS. They discuss in groups and write down possible explanations to the phenomenon observed in this first experiment, **using scientific expressions and scientific reasoning**. They may discuss their explanations with other groups or groups.
16. 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.

    The teacher may summarize their ideas in one list.
17. At the end of activity students take individual notes summarizing what they learned or what they have heard from their colleagues but not noted yet.
18. 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 a homework and/or treated as a revision of learning.

Assessment methods incorporated into IBL

Formative assessment: (1) self- and peer-assessment of a group work, preferably combined together and compared by the teacher later on; (2) rubrics for evaluation of: formulating a research question, putting forward hypotheses and/or planning the experiment.

Summative assessment: a scientific reasoning test with additional tasks on design of an experiment.

Coach's Advice

- It is very much important to gather as much context knowledge as possible during the brainstorming at the beginning of the implementation. It is a teacher's task to make sure that students know different types of friction and they distinguish them.
- Depending on the class level, time that can be devoted for this activity and curriculum content, the teacher can ask students to investigate the influence of the same factor on the same type of friction or distribute among

groups the tasks of studying the impact of different factors on different types of friction. Particularly in the latter approach, it is very much important for a teacher to monitor the final notes and make sure they are complete and consistent among all students in the classroom.

- The activity can be implemented in many curricula contexts, at different levels of advancement in physics. A simple guided IBL can be done, if the teacher selects one factor that influences one type of friction and asks the students to investigate it. More advanced scenario has been presented above. It is also possible to organize an open inquiry, in which the initial task is given not as a research question formulated (or quasi-formulated) by the teacher, but as a problem: Investigate friction.

Coach's Learnings from implementation during the 3DIPhE workshops

If implemented during the PLCT workshops It is advised to introduce this learning unit during the second or third meeting when teachers learn about different levels of inquiry. Friction is also a very good topic for teachers' practice on brainstorming in the IBL method.

Supplementary material

A worksheet for students is available in an editable form and as a pdf. The pdf form fits to A4, to see the outlook of a booklet. This may change if its editable form is adapted to specific needs of a certain inquiry.

3D_IBL_Worksheet_Friction_UJ.docx

3D_IBL_Worksheet_Friction_UJ.pdf

A teacher guide for an IBL lesson using the worksheet is meant for a teacher and does not need printing if the teacher is used to reading on screen. Both forms, the docx and pdf are available.

3D_IBL_Guide_Friction_UJ.docx

3D_IBL_Guide_Friction_UJ.pdf

1.3.3

Penumbra and the spreading shadow

Mojca Čepič, Maja Pečar and Ana Gostinčar Blagotinšek, SI

The unit was developed by Mojca Čepič, Maja Pečar and Ana Gostinčar Blagotinšek, from University of Ljubljana, Faculty of Education, Slovenia.

Context and goals

Penumbras, half-shadows or semi-shadows are an everyday phenomenon, which could be observed almost always when an extended light source illuminates an object which casts a shadow (Fig. 1a). Unfortunately, the concept of the penumbra is usually discussed only in astronomy of nearby celestial objects and eclipses. Although it is omnipresent in everyday life, the penumbra is seldom studied in school and remains detached from students' everyday life.

The activity presented here is simple, does not need sophisticated equipment and is not time demanding. It allows the students to study reasons for penumbra's appearance and its properties related to the shape of the light source and the position of the object.

In addition, to students who finish early, the teacher could demonstrate another phenomenon, the spreading shadow. The teacher can use the setup for studying the penumbra and follows the instructions given in the continuation. Students continue with the inquiry of conditions for the spreading shadow to appear on their own and try to explain why this interesting phenomenon occurs. The phenomenon can also be observed in sunlight, when two objects cast a shadow to the screen (Fig. 1b)


(a)


(b)

Figure 1 (a) Penumbra is a region where a dark shadow continuously transforms to a bright region. Here, the shadow of a building in sunlight. (b) A spreading shadow occurs when penumbras of two different objects meet. Note the shape of the shadow of a rectangular paper (left) when a shadow of two fingers (right) is close. Also this phenomenon could be observed in sunlight as presented here.

The main goal regarding the knowledge and comprehension of this unit is

- to acquire terminology for discussing shadows/umbras and penumbras and conditions to their appearance.
- to learn two modes of observation of umbras and penumbras and to determine their edges.

In addition, the activity could be used to train or test ray diagrams in an interesting and motivating way. Extension of the activity, that is, the spreading shadow, is more demanding and inquiry is quite open. The learning goal for the extended part is that a shadow is not always connected to a single object but more objects can be a reason for a single shadow.

GOAL	• to train/improve the observation skills • to determine independent and dependent variables • to properly control variables • to encourage predictions • to design measuring methods • to accompany the reasoning with sketches/drawings • to draw conclusions • to learn something new from everyday life
IBL LEVEL	Guided inquiry with an open inquiry extension.
AGE & SCHOOL TYPE	Appropriate for all levels when students, who are already familiar with shadows, know the difference between a point-like light source and an extended diffuse light source. If not, the teacher can explain the difference. Knowledge of ray diagrams and presentation of light in general is expected.
GROUPING	• 2 – 4 students • randomly formed groups with respect to ability, gender and friendship by drawing cards; • desks for two persons or two individual desks together; the desk has to have 1 meter at least in length.
IBL unit resources	Adapted from M. Poklinek Čančula, M. Čepič, »A spreading shadow in color«, Phys. Teach. (2017) 55, 5862018.
Key concepts	shadow/umbra, semi-shadow/penumbra, ray diagrams, extended light source
Inquiry skills developed	• planning investigation • working collaboratively • drawing conclusions • presentation of the results • articulating predictions • forming coherent arguments
Scientific reasoning	• identification of variables • making scientific connections • making comparisons • identification of reasons
Scientific literacy	• evaluate and design scientific investigation • presentation of scientific data (sketches, drawings of ray diagrams) • scientific explanation of concepts (use of scientific expressions) • scientific explanation of phenomenon • bridging – relevance for everyday life
Assessment	• ray diagrams • terminology characteristic for the phenomenon • measuring illumination by lux meter or by simple means

Unit description

1. Introduction

The activity is focused on two phenomena, a penumbra or a semi shadow that is formed when a light from only a part of an extended light source is absorbed in an object (Figure 1a), and on a rare phenomenon one can observe in everyday life, when he/she is aware of what to observe. This second phenomenon is called a spreading shadow (Figure 1b) and occurs when the penumbras of two different objects overlap.

2. Introductory activity for students

The students first recreate the circumstances that allow observation of penumbra using equipment provided by the teacher. Next, they investigate the phenomenon for a while to gain experience.

Equipment per group

- One elongated diffuse light source. Easily accessible are lights for illumination of a camping site or working. These lights have to be plugged in electricity (220 V) regularly (Fig. 2). Suggested dimensions are from 30 - 50 cm of length and a width of few cm with one fluorescent tube only. Do not use lights with a stripe of point-like LED light sources, as phenomena could not be observed well.
- A self-standing white screen of A4-A3 paper size dimension.
- Two rectangular black pieces of cardboard as objects whose shadows are observed. It is advisable to provide holders for the cardboards like the ones in Fig. 2 or alternatively, shape and fold the bottom part of the cardboard with 2 cuts of 2 cm length and fold the pieces to the opposite direction (Fig. 3). If a group has more than three students, two of them can hold the cardboards by hand.
- Mobile phone with a camera.
- Sticky tape, white paper and pencils for marking the area of s shadow.
- Scissors, if students themselves make self-supporting cardboards.
- Dark/black cloth or paper to prevent reflections from the desk, if desks are shiny (see Fig. 2).

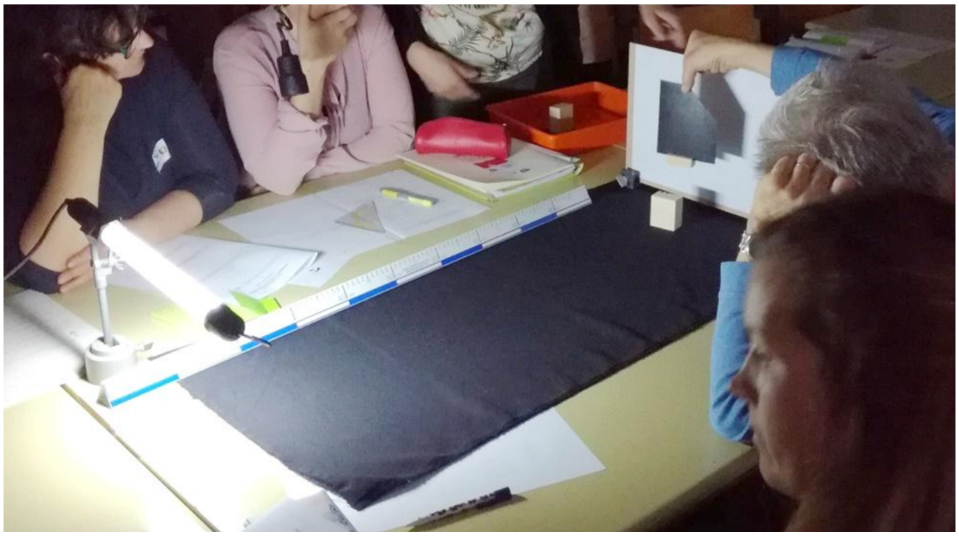


Figure 2 The setup for an inquiry of penumbra.

The light source is fixed with a long side horizontally to one side of the desk about 30 cm above the desk surface. The white screen is fixed in a distance between 80 cm to 1 m away from the light source at the opposite side of the desk. These two stay fixed through the whole inquiry. The dark cloth or paper is placed between the light source and the screen (Fig. 2). Students are instructed to assemble such settings or it is prepared in advance.

Students are instructed to inquire about the shadow of an object/black cardboard on the screen, its shape and the region around the shadow. They can change position or orientation of the cardboard.

The teacher stimulates investigations with questions, if some participants do not "play", for example: Can you show me your shadow and the area around it? In which direction the transition from dark to bright area is wider? How would you determine the borders of this transition region?

When students gain some experience with the shadows, the teacher introduces terminology and modes of observation of shadows. He also gives students the text "3D_IBL_text_Shadow_terminology_UL.pdf" found in Appendix A or its translation.

3. Forming inquiry question

For this step it is advisable that the inquiry is guided. The teacher uses 3D_IBL_Guide_Penumbra_UL.pdf in Appendix B for her/his preparation and students make their notes to the printed version of 3D_IBL_Worksheet_Penumbra_UL.docx/pdf found in Appendix C.

The teacher's guide for this activity and the worksheet for students are provided as a separate downloadable document. For resuming partial results during inquiry, the teacher can use the poster size printout of 3D_IBL_Poster_Inquiry guide_UL.pdf found in Appendix D attached to a white board.

From now on, the plane of the objects casting shadows, that is, the black cardboards, should be parallel to the screen. They can still be rotated around a horizontal axis perpendicular to this plane ensuring that the orientation of the plane of the cardboard remains the same.

Teacher asks students to show the penumbra region and to quote properties/circumstances that influence the penumbra's appearance (frame 2 in the worksheet) and to quote properties of penumbra they find important (frame 3 in the worksheet).

Two variables are evident and are almost always suggested – the width of penumbra and the contrast of the shadow. Sometimes students try to discuss the color of penumbra as well.

The teacher encourages students to study the effects of independent variables on the width of penumbra. But before they start to measure its width, they have to agree on the methodology to determine the edge of a penumbra, which is not a trivial question.

Students usually try to measure the width of penumbra by direct observation of a shadow brightness. If doubts about deciding the edges of a penumbra do not occur during a discussion in a group, the teacher stimulates this doubt by asking students to substantiate the decision, where to define the edge. In addition, the teacher asks what they would see, if they "stay" at one of the edges. This can be verified by placing a mobile camera in that position and observing the screen of the camera. This second type of observation gives detailed information which parts of the light illuminate the screen.

4. Why does the penumbra occur?

Both activities, the observation of brightness and the observation of the light source partially covered by an object result in comprehension that a penumbra is a region, where only a part of the light source illuminates the screen.

In addition, the region of penumbra is defined by two points, the dark point is the point, from which further to the shadow the light source is completely obscured by the object, and the bright point is the point, from which away from the shadow the light source is not obscured by the object any more. Logarithmically sensitive eye does not detect these two points by a simple observation of brightness.

5. Expected explanations, testing experiment, prediction of outcomes and their meaning

From the previous explanation, drawing ray diagrams leads to the connection between distances of the object from the light source/screen and the width of the penumbra.

Each explanation drawn by a ray diagram or just articulated in speaking or writing could be immediately tested. This makes a cycle of predicting, testing, improving a prediction very easy, fast and motivating. The teacher may encourage "playing" and drawing conclusions first, and drawing neat ray diagrams after the group decides for the interdependence of the width of penumbra and distances.

This inquiry unit is also interesting to discuss the independent variables. It turns out that for the fixed distance between the light source and the screen, one distance, from the object to the screen for example, already determines the other distance, that is, the distance from the object to the light source. Although both variables can be suggested separately as independent variables, only one satisfies. In inquiries, it is often the case that one cannot strictly control all other variables, but some of them often depend on a chosen independent variable. Nevertheless, the condition of the fixed distance between the screen and light source can be released in the final part of inquiry to allow students to find optimal setup for reporting and demonstration to the colleagues.

The first part of inquiry is finished at this point. The groups report their findings and the teacher takes care that all students have "institutionalized notes": The teacher verifies that results of the inquiry are findings consistent with the scientific knowledge. If the findings of the groups are different, the teacher needs to examine processes in different groups and the credibility of their findings. Some groups might be asked to repeat the experiment.

6. Extending this inquiry – A spreading shadow

If a certain group is quick and has still some time available, the teacher demonstrates the spreading shadow. She/he places one cardboard with sides placed perpendicularly about 20-30 cm from the screen that a shadow of this object has a few cm of penumbra in direction parallel to the longer dimensions of a light source. The teacher takes the second cardboard and rotates it in such a way that the plane of the cardboard is still parallel to the screen, but sides of the cardboard make an angle of 45˚ with the vertical sides of the other object. The teacher holds this second cardboard in her/his hand about 10-20 cm from the object toward the light source in a way that it casts a shadow to the screen and the shadows of both objects are clearly separated. The second cardboard is slowly moved parallel toward the first object and the shadow of the second object and its penumbra slowly approaches the shadow and penumbra of the first object. Students have to observe the shape of both shadows when they are close.

Before starting the inquiry, students are asked to clearly articulate and write in their notes the observation. After that they can start to "play" inquiring conditions to observe the phenomenon and search for explanation. Encourage them to draw separate ray diagrams for each shadow and join them afterwards in one picture.

The spreading shadow occurs due to the overlapping penumbras of the two objects. One object absorbs the light from one part of the light source, the other from another and when both cover the whole light source, the full shadow appears in the region of the penumbra of the first object. This gives an appearance of a shadow, which is growing from one object toward another and has a shape of the second, more distant object. The phenomenon is well observed in the region, where penumbra is wide. If the more distant object approaches the object from above, perpendicularly to the long side of the light source, the phenomenon is barely observed or not at all.

7. Conclusions

Shadows are an everyday phenomenon that is discussed at the elementary level but is later almost forgotten in curricula. The phenomena related to shadows might be very interesting, if one considers reflected light or extended light sources. Careful observers can notice those phenomena in everyday life, but it is seldom the case. Therefore, it is worth intentionally setting the circumstances which allow for their observations, to inquire the reasons for them and afterwards search for them in nature. Our Sun is an extended light source and it enables us to observe penumbras and a spreading shadow to a careful observer.

Both activities, the penumbra and the spreading shadow, could be divided to two separate activities and accompanied by worksheet for students 3D_IBL_Worksheet_Penumbra_solo_UL.docx/pdf and 3D_IBL_Worksheet_Spreading_shadow_UL.docx/pdf in Appendix E. If students carry out the spreading shadow activity after the activity on penumbra separately, about 40 minutes is needed.

Assessment methods incorporated into IBL

Formative: The activity is appropriate for students that are already familiar with ray diagrams, the concept of extended diffuse light source and the ray diagrams presenting such sources. If not, the concept is introduced after students gain the introductory experience.
At the end of activity students should be able to connect both types of penumbra observations, the observation of the brightness of the shadow area and the observation through an eye of a mobile camera which clearly also shows the parts of the light source that illuminate the area where the objective of the mobile camera is placed.
Correct drawings of ray diagrams demonstrate a students' comprehension of ray diagrams and enable them to develop an explanation for the second part of inquiry – the spreading shadow.

Summative: Ray diagrams of similar setups can be used for verification of understanding of penumbra and ray diagrams in written tests. More demanding tasks are related to the active observation of shadows. For example, the object in Fig.3 casts a shadow on the screen. Ask the student to draw what the camera would show if the picture is taken from one of positions 1 – 6 marked at the picture.

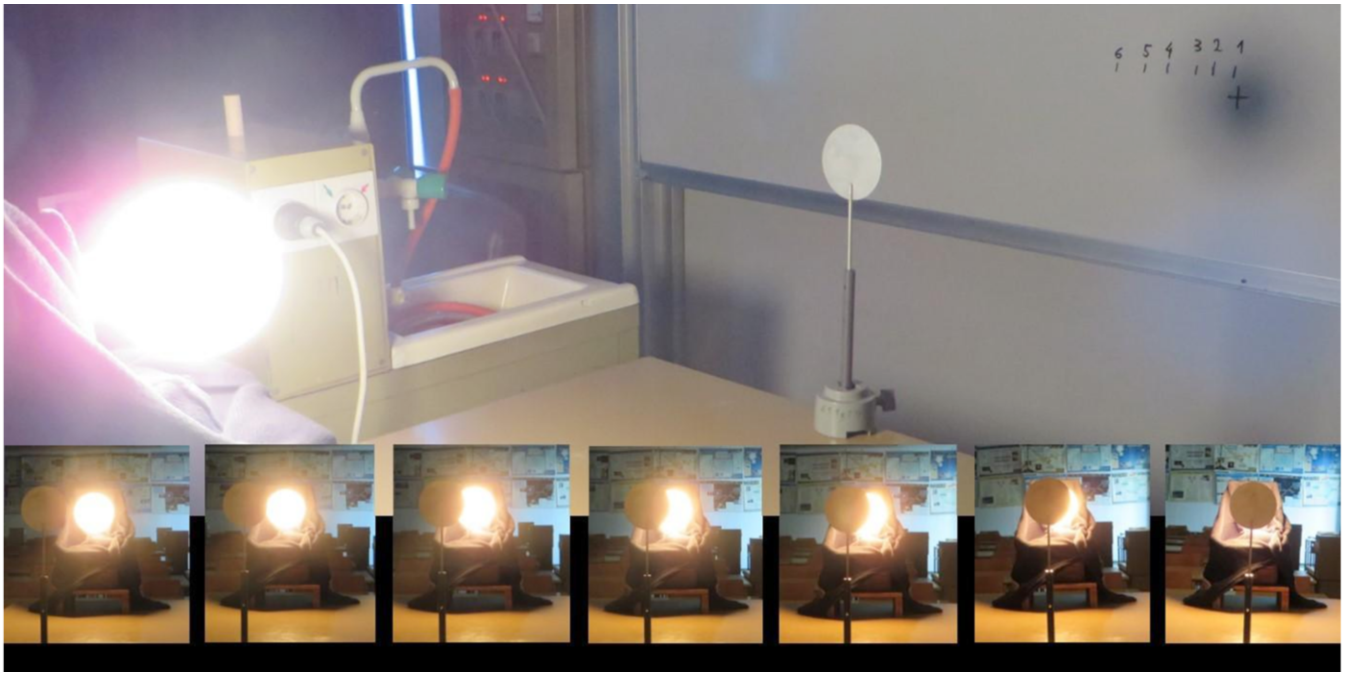


Figure 3. A diffuse light source (left) illuminates a circular flat object, which casts a shadow with an extensive penumbra. The pictures below were taken from marked positions on the screen. The first picture at the right was taken from the position marked with a + and the camera moved horizontally to the left taking a picture in position 1, 2 to 6, which was already outside the penumbra.

Coach's Advice for implementation in the classroom

Allow at least 90 minutes for the implementation of the unit. It is advisable to fix the light and screen to desks in advance. The working sheets can be edited and separated into two, the second dealing with a spreading shadow separately and the second one is given to students, if they finish the penumbra inquiry early. On the other hand, the spreading shadow is a very interesting phenomenon and can be carried out as a separate activity after the penumbra activity in 40 minutes. The separated working sheets are also found in Appendix E.

Coach's Learnings from implementation during the 3DIPhE workshops

The activity was carried out with a group of expert PLCT at the end of the first year. Next, it was carried out during the small local multiplier event with almost 40 teachers, and members of the expert PLCT acted as facilitators of groups carrying out inquiries. The same activity was carried out at the National meeting of science teachers, where around 50 teachers joined.

The schedule at both events allowed for 60 minutes, which turned out as short. Nevertheless, all teachers compared the passive and the active observation of penumbra and realized the difference and how they are connected. The spreading shadow was demonstrated quickly, but the time allowed for inquiry of reasons and most of the groups figured out reasons for the occurrence of the spreading.

Supplementary material

The text which introduces new concepts like "penumbra" and the modes of its observation 3D_IBL_Text_Shadow_terminology_UL.pdf and in its editable form, which allows for either including it into the worksheet or shortening it if appropriate, because some concepts are already known to students, is 3D_IBL_Text_Shadow_terminology_UL.docx.

The guide for a teacher is found under name 3D_IBL_Guide_Penumbra_UL.pdf, and in its editable form, which allows for copying pictures, modifications and notes for later use is 3D_IBL_Guide_Penumbra_UL.docx.

The worksheet for students is found under name 3D_IBL_Worksheet_Penumbra_UL.pdf,
and in its editable form 3D_IBL_Worksheet_Penumbra_UL.docx.

Poster for leading the inquiry based learning for beginners.

3D_IBL_Poster_Inquiry guide_UL.pdf

Separated worksheets for penumbra and the spreading shadow for students.

3D_IBL_Worksheet_Penumbra_solo_UL.pdf, 3D_IBL_Worksheet_Penumbra_solo_UL.docx,
3D_IBL_Worksheet_Spreading_shadow_UL.pdf, 3D_IBL_Worksheet_Spreading_shadow_UL.docx

1.3.4

Plasma Spheres

Jan De Lange, BE

Context and goals

The unit was developed by *Jan De Lange* from Artevelde University College.

Important note: *This is an activity for teachers and is not meant for students, so goals & activities are described for teachers. However, we notice that teachers are copying and adapting some of the activities in the context of their classroom.*

GOAL	The provided material describes plasma physics workshops for teachers in which they learn certain contents and didactical methods by experiencing a learning sequence of IBL themselves. This will help teachers create a teaching unit for physics classes in schools. The topic of plasma is not known very well by students and teachers as well. However, because of these unfamiliar phenomena and knowing what it is about, it sparkles curiosity and fascination. This context of plasma spheres is a good and authentic context for promoting IBL.
IBL LEVEL	Open inquiry
AGE & SCHOOL TYPE	For all teachers of secondary schools (all grades and levels)
GROUPING	Groups of 2-3 teachers, randomly chosen.
IBL unit resources	This activity uses the context of plasma spheres, but an IBL unit at student level does not exist (because it is not the purpose of using it at student level).
Key concepts	Key science concepts • the definition of plasma as the fourth state of aggregation, • appearance of plasma in nature and technology, • methods to generate plasmas, • atomic excitation and light emission, • gas discharge, • the general functionality of a plasma sphere, • gas identification and spectroscopy.
Inquiry skills developed	• Generating ideas and questions in discussion and through observations, • Drawing conclusions • Presentation of the results
Scientific reasoning	• Classification
Scientific literacy	• Understanding the real-world context of the topic

Unit description

1. Introduction to the topic
    a. Brainstorming: Making associations with the word plasma and **collecting prior knowledge**
    The teacher asks general questions to find out what students know about plasma. Possible answers and ideas are discussed with all students (not in groups) and summarized at the blackboard. Possible questions: What is plasma? What do you think of when you hear the word plasma? What do you know about plasmas? What do you want to know about plasmas?
    b. Short lecture on key characteristics of plasma: This topic is not very well known to students and teachers. However, plasma occurs in a lot of everyday life experiences. They start **to understand the real-world context of the topic.** This presentation gives a short overview (plasma in lightning technology, in nuclear fusion research, in nature). The presentation about these plasma phenomena can be found here.

2. **Observations** of the plasma sphere.

After the introduction participants can explore the plasma sphere for the first time through specific observations. Plasma spheres are pretty unknown to them and therefore sparkle their attention and enhance their motivation to start. It is important they only observe and describe different phenomena without trying to find explanations of inferences. Some tips:

- An observation is something you see, smell, hear, feel, … about certain phenomena.
- They can be qualitative or quantitative. In qualitative observations we use a lot of adjectives to describe our observations, whilst qualitative observations are expressed by numbers.
- Don't make conclusions or inferences. Reflect on your observations a lot by looking if it is not a conclusion or interference.

Encourage participants to write down at least 10 observations, first by not touching the ball and only then by touching it with one finger. Collect those observations on the blackboard and discuss differences between observations and inferences.
Possible results:

	observations
Without touching	lots of streamers, streamers are pink-blue-pink, move around fast, object/ human approaches: streamers change direction and speed the bigger the area of touching the bigger the streamer, buzzing, black field in middle, from bottom up; streamers split up at top;
touched by finger	only one streamer; two fingers: connected by streamer; development of heat; still smaller streamers there, but less than before; streamers headed towards finger; weak prickle/ tingle; streamer jumps between these two fingers; smells like chlorine/ ozone/ solarium; finger smells burned; vibrations; when touching, buzz gets louder; bigger streamer

3. **Raising questions** and **key ideas** about plasma

Participants must generate as many questions as possible about what they want to know about plasma. If necessary, the coach should refer to the phenomena described in the introduction and also to the observations. Divide in small groups and designate a 'reporter' to write down all questions. Every question related to the topic is a good question; even it is not possible to answer it.

A possible list of questions:

- Polar light: why at the poles only?
- Can you touch/see plasma?
- What color has plasma?
- State of matter: why the 4th?
- How can plasma be produced?
- Is plasma dangerous? Can it be "misused"?
- What is the connection between plasma and TV?
- Why do plasmas emit light?
- What is it made of?
- What can influence it?
- Why does it move? Can it stand still?
- What is the temperature of the plasma?
- Why different colours?
- Why does the plasma stay inside the sphere?
- How does the plasma sphere work?
- Can plasmas go everywhere?
- How can plasma be kept?
- Can you touch plasma?

This list of the **questions** can be **categorized** in different topics like heat, light, matter, danger, etc.
In the end, a set of categories with different questions is available.
Then, participants are assigned to groups that work on one of the categories.

If time is available, participants could work on different questions by looking for some theoretical information. However, this is very time consuming. You can present some theoretical information (basic!) on plasma with the presentation.

4. **Experimental investigation** of the plasma sphere.

Instructions:

- Participants work in small groups.
- Encourage them to investigate several things that can be inquired and observed using the plasma sphere. Provide extra materials like needles; copper wires, paper, aluminum foil, magnets, different gases, water, multimeter, coins, lamps, LED's, etcetera.
- Let them freely explore with lots of objects and different setups. The explorations have no limits.
- If time is available, participants can search for explanations and answer using laptops, but this is not crucial. The important thing is not to stop making observations, raising questions and formulate good (inquiry) questions.

Important note about the questions being investigated. Good inquiry is always driven by specific and well formulated inquiry questions. However, within the context of plasma spheres, this is a rather difficult aspect. A lot of questions will be formulated as 'why something happens' and for this reason not quite good as an inquiry question. You can search for explanations in literature or on the internet, but they do not lead to certain specific actions that you can do during investigations. However, they will certainly arise questions written in the format like 'what happens with … if I do …?'. White presenting the investigations in the next stage, it is good to discuss the value of raising questions and the difficulty of turning it into a good inquiry question. When they are able to formulate such questions, they will be more focused in their inquiry and come to better results.

5. **Presenting results**

Participants present their results. These will be mostly descriptive (and not quantitative data). Results must be collected, ordered and discussed.
If possible, discuss with your group different inquiry questions (see important note above).

Assessment methods incorporated into IBL

Formative: during group discussion and dialogue all participants are reflecting about what they have learned (a classroom dialogue tool).

Coach's Advice (for implementation during coaching of teachers) and coach's Learnings from implementation during the 3DIPhE workshops

- Most of the activities do not depend on each other and according to this, certain activities can be skipped or taught separately. If there should not be enough time to research their questions autonomously, a short lecture can be given instead.

Supplementary material

- Materials list: Magnets, Paper clips, Candles, Nails, Plasma balls, Tl-tubes, Copper wire, Various metal wires, tubes, conductors, Copper coins, Aluminum foil, Needles, Low-energy lamps, Tubes with gases such as Ne, Ar, He, Na
- Presentation about plasma phenomena
- Presentation about plasma (basic theoretical background)

Pressure

Mojca Čepič and Ana Gostinčar Blagotinšek, SI

The unit was developed by Mojca Čepič and Ana Gostinčar Blagotinšek, from University of Ljubljana, Faculty of Education, Slovenia.

Context and goals

When estimating the weight of the objects by weighting them in our palms we can be easily deceived because the receptors in our skin are in fact comparing pressure. Comparing the "weight" of two balls (chosen in the way that a bigger one is also heavier) gives a false result: a smaller (and lighter) one feels heavier. As subjective impressions are not reliable, the experiment with the balls is repeated objectively, on the air cushion, which again compresses more under the lighter ball (Fig. 1).

The experiment

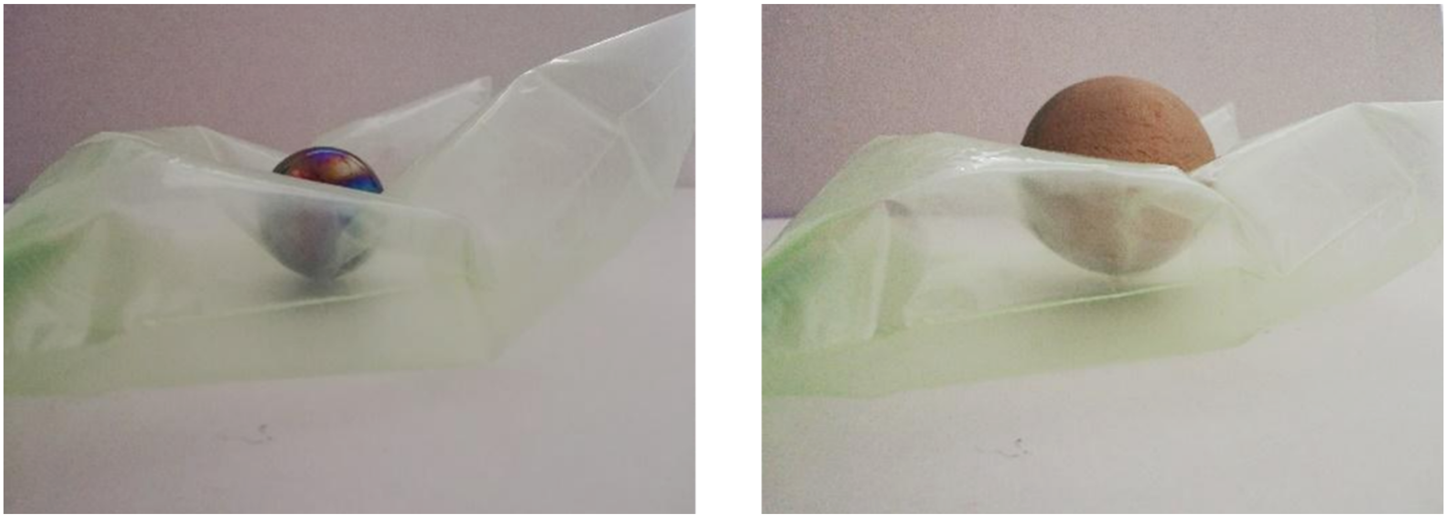


Figure 1: Smaller sphere sinks deeper in the air cushion (left) than the bigger (and heavier) one (right).

Spheres are then weighted on the scale, to present the problem and cause a cognitive conflict. Heavier sphere feels lighter and Looking for other property(-ies) which causes such results can be done in the form of inquiry and can lead to introduction of pressure in physics lesson or be used as a demonstration of a necessity to define another physics quantity besides mass to be able to describe object's influence on the surroundings.

GOAL	• to train/improve the observation skills • to distinguish between objectively and subjectively derived properties • to encourage predictions • to design testing experiments • to draw conclusions • to understand importance of pressure as a physical quantity
IBL LEVEL	Structured inquiry
AGE & SCHOOL TYPE	Appropriate for lower secondary / when the pressure is first introduced; as inquiry exercise also for primary, when mass and surface area measurements are mastered
GROUPING	• 2 – 3 students • randomly formed groups with respect to ability, gender and friendship by drawing cards; • desks for two persons or two individual desks together
Key concepts	pressure, mass, surface area
Inquiry skills developed	• planning investigation • working collaboratively • articulating predictions • designing testing experiments • presentation of the results • drawing conclusions and interpretation
Scientific reasoning	• objective and subjective determined properties • identification of variables • making scientific connections • making comparisons • identification of reasons • transfer of learnings in a new context
Scientific literacy	• evaluate and design scientific investigation • scientific explanation of concepts (use of scientific expressions)

Unit description

1. Introduction

Lesson starts with comparing weight of two spheres made of different materials, masses and diameters (wood: 2r = 5,8 cm, m = 88 g, glass: 2r = 3,6 cm, m = 64 g in this example), observing their impact on an air cushion (getting similar results, pointing to a smaller sphere to be "heavier" and also compressing the air cushion more) and then using a scale to determine that the mass of the bigger one is actually bigger.

Materials (for the whole classroom):

- two spheres (balls) of different materials, masses and diameters (wood: 2r = 5,8 cm, m = 88 g, glass: 2r = 3,6 cm, m = 64 g),
- a zip bag,
- kitchen (or similar) scale.

It is probably impossible to find exactly equal spheres as the ones presented here, but any pair of spheres with similar dimensions and weights would do.

For steps 2-8 you might also use the poster to guide inquiry which is found under the name 3D_IBL_poster_Inquiry guide_UL.

2. Identifying possible (independent) variable(s)

Two spheres have different masses, but are also different in other ways; a conclusion that some (at least one) other property influences our sensations in the skin and also the impact on the air cushion seems feasible. Students should identify as many differences between the spheres as possible, improving their observation skills.

3. Identifying possible (dependent) variable(s)

Comparing the sensations is not an option; objectively determined depth of sinking should be compared (measurements are not reliable and repetitive enough).

4. Choosing independent variable

If the teacher wants the inquiry to develop into a lesson on pressure, the chosen independent variable to study effects of spheres on the surface below them should be the size of the contact area between the sphere and the surface underneath it.

5. Choosing dependent variable

The choice to compare depth of sinking into the air cushion or the amount of compressing it is straightforward.

6. Listing constants/controlled variables

All variables which students listed in step 2 should be monitored and not changed at all (if this is not possible, they should change as little as possible) – except our chosen independent variable (quoted in step 4). Mass of the object(s) has to be constant.

7. Forming the inquiry question

The form to help students form the appropriate question is supplied (What will happen with ... (dependent variable quoted in 5.) if .... (independent variable quoted in 4.) changes/increases/decreases?). This unit is meant to lead to introduction of pressure, so the influence of the size of the contact area on the depth of sinking/amount of compression should be the scope of inquiry

8. Forming the hypothesis, educated guess

Forming the hypothesis about the outcome of the inquiry and justifying their statements should focus students on the inquiry question and help them reflect on what they already know or have experience with – related to the current problem. It is not important whether the hypothesis is correct.

9. Planning the inquiry

a) What we plan to do and how?

b) What do we need (list of experimental equipment and other tools)?

c) Which data will be collected? How will we record it?

Additional questions are a scaffolding for the students.
Equipment per group (Fig. 2):

- a zip bag,
- 2 cardboard rectangles with different surface areas, adjusted to the size of zip bag, and/or
- metallic or stony brick.

Zip bag should be filled with air in advance by the teacher and carefully sealed. Ideally the object sits on the surface beneath it when it is put on its smaller side surface/smaller cardboard. Students should place the same object (assuring that the mass is constant) on the air cushion, changing only the side surface which is in contact with the air cushion (and the size of the contact area with that). Another alternative is using two cardboard rectangles with very different surface areas and putting the same object on each of them in two consecutive experiments.

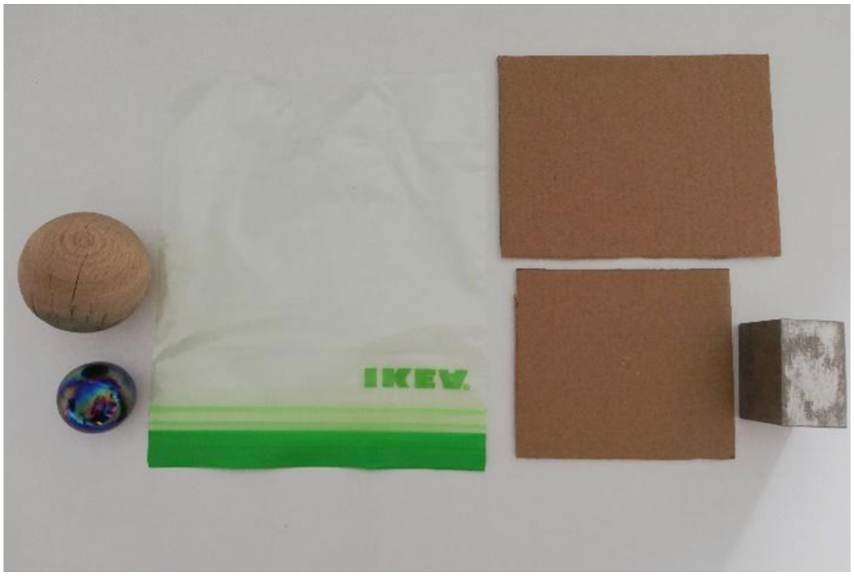


Figure 2: Materials for inquiry about pressure.

10. Conducting the inquiry and interpretation of the results

This inquiry is very structured; students should be prompted to stick to their plans or record any necessary changes. The recording of the observations/measurements should be encouraged. The results should not be reported in form of confirming/rebuffing the hypothesis; it should be the answer to the inquiry question in a full sentence.

11. Conclusions and presentations of inquiry; relevance for the initial problem

Reported results should have the form of "The smaller/bigger the contact area, the greater/smaller is the depth of sinking in the air cushion despite the object being of the same weight.

The heavier ball from the initial experiment is also bigger and presses on the surface beneath it in a bigger area than the smaller one. The combined result of the weight and contact area is what we really feel on the skin and what is important for how much the air cushion (or any surface for that matter) is compressed by an object.

The findings of the inquiry offer a possibility to introduce pressure (p) as a physics quantity (and also justifies introduction of yet another definition which has to be learned by heart).

Assessment methods incorporated into IBL

Formative: The activity is appropriate for beginners in IBL, as it is very structured. The ability to stick to the plan of the inquiry and transformation from knowing the principles of fair testing in theory to operationalize them when planning a concrete (although simple) experiment should be monitored (e.g. by use of rubrics).

Summative: Keeping focus on the planned activity and using the findings to explain the initial brain teaser demands transfer.

Coach's Advice for implementation in the classroom

The choice of the right combination of the equipment is crucial. The balls should be similar to those, described above, to cause the initial cognitive conflict. For the expected observations during the inquiry, the appropriate air cushion and the amount of air inside, sizes of the cardboards and masses of object should all be carefully matched to enable comparison of the effect with a naked eye. Measurements of the depth of sinking seem deceivably simple, but are not reliable, because small shifts of the object on the air cushion cause the air cushion to shape very differently.

As pupils focus on confirming or rejecting their initial hypothesis, the correctness of the hypothesis should be emphasized as irrelevant. Reporting should focus on meaningful statements about the effect of independent variables (contact surface area size) for the dependent one (depth of sinking into the air cushion).

Coach's Learnings from implementation during the 3DIPhE workshops

The activity was tested with the Slovenian group of teachers who find it inspiring because of the initial cognitive conflict, useful for the motivation. The varieties of the described experiments are well known, but this version is more portable than f. i. bricks on the sponge rubber and accessible in quantities, suitable for group work and therefore making the lesson more active for the students.

Supplementary material

The worksheet for students is found under name 3D_IBL Worksheet_Pressure_UL.pdf,
and in its editable form 3D_IBL Worksheet_Pressure_UL.docx.

The guide for a teacher is found under name 3D_IBL Guide_Pressure_UL.pdf, and in its editable form, which allows for copying pictures, modifications and notes for later use is 3D_IBL Guide_Pressure_UL.docx.

Poster to guide the planning the inquiry is found under name 3D_IBL_Poster_Inquiry guide_UL.pdf.

1.3.6

Rainbow in a box

Dagmara Sokołowska, PL

The tool was developed by Dagmara Sokołowska from Jagiellonian University, Krakow, Poland, Faculty of Physics, Astronomy and Applied Computer Sciences.

Context and goals

Light is one of the most important conditions of a normal existence of a human being. Every day we use light to be able to see objects, distinguish colors etc. Also the light properties, like reflection, refraction, dispersion or splitting of light are commonly experienced, although maybe not always recognized properly.

One of the most spectacular phenomena is the appearance of a rainbow. Not everybody knows that the rainbow is not formed in the far distance, in the Sky, but actually in the eyes of the observer. White light rays coming from the Sun get into the small droplets of water suspended in the air in front of the observer. They are twice refracted and split, and come back towards the source of the light, however scattered in a broad angle regime. One point in a distance (e.g. the eye) is reached by many rays, each of a different, but specific wave frequency. They all come from different droplets of water suspended in the air.

We are able to observe the splitting of light also in other circumstances, i.e. on the surface of a CD, or when the light passes the prism or the diffraction grating. If the source of light emits the entire visible spectrum of light, one can observe a continuous spectrum of colors. However the gaps in the spectrum may occur, if the source does not emit some parts of the visible light band.

A spectroscope is a tool that enables observation of the spectrum of visible light from different sources. It can be constructed from everyday materials, like a cardboard, a piece of a CD and a tape. Such a primitive, home-made spectroscope is good enough to detect differences between the light sources available on regular basis and even – to detect the elements in the spectral lamps.

GOAL	Comparing different sources of light through their spectra. Detecting the elements emitting light in spectral lamps.
IBL LEVEL	Building the spectrometer: STRUCTURED, investigation of different sources of light: GUIDED
AGE & SCHOOL TYPE	• Most appropriate for the light topic in lower secondary (14-15) or upper secondary school (17-19). • Can be used also with younger students some of the text in a worksheet for students could be left out or rearticulated to more simple expressions.
GROUPING	• preferably 2-3 students per group • depending on the teacher additional interest, groups can be formed by random or with special focus on gender or student ability composition • groups can be formed by a teacher or students themselves
IBL unit resources	Coach's original material, inspired by https://www.scienceinschool.org/2007/issue4/spectrometer

Key concepts	Light as electromagnetic wave, reflection, refraction, dispersion, splitting of light; diffraction, interference
Inquiry skills developed	• generating ideas in the discussion • developing hypothesis, • forming coherent arguments, • working collaboratively, • observation skills, • drawing conclusions • presentation of the results
Scientific reasoning	• making scientific connections, • choosing right components, • making comparisons
Scientific literacy	• reviewing prior knowledge • understanding the properties of physical quantities, • scientific explanation of concepts (use of scientific expressions) • scientific explanation of phenomena, • understanding of physical quantities, • understanding the real world context of the topic • searching for information in external resources

Unit description

Below the implementation of the unit is described in details in a chronological order. Parts of the description related to the Guide for teachers are marked in blue.

The activity takes ca. 2 lesson hours, preferably in a row. During the entire implementation students take notes in their worksheets.

1. At the beginning of the first lesson the teacher organizes a brainstorming, in which students recall and **review** together their **prior knowledge** about light, its function in everyday life, **light properties and phenomena** related to it. The phenomena are named with **use of scientific expressions** and they are distinguished. An extended course of the brainstorming is provided in the Presentation. It should be noticed that some parts may be omitted or modified, depending on students' age, school curriculum etc.
2. Students are led to the idea of diffraction and interference and to the diffraction grating.
3. In the next step students are given an instruction on how to construct a spectroscope with use of everyday materials. They work individually, but help each other in understanding the construction steps and in assembling the parts together.

At this point the second lesson starts

4. Student start **observations** of everyday sources of light: the Sun, a tungsten bulb old type, new energy-saving types of electric bulbs, a screen of a computer or laptop. Students **take individual notes** on their observations. They start in groups a **discussion** on similarities and differences among observed spectra.
5. Each group **shares its results** with other groups. Students try to **formulate conclusions** and **give** possible **explanations**.
6. Teacher puts together all the results and continues with more scientific explanation of the phenomena of spectrum from high density hot matter, hot gas and cold gas.
7. Subsequently students observe the fluorescent lamp (with mercury gas inside). They **identify the full spectrum** and some brighter, **narrow lines** in the violet-blue-green part.

8. Students discuss this difference in a group or in the whole class. The teacher helps with explanation with the Bohr's model, included in the presentation.
9. The teacher lights on a candle, pours some kitchen salt onto a metal knife and places the knife in the middle off the flame. After waiting a few minutes, the salt starts sparkling. Students observe the light through their spectroscopes and take notes. Afterwards they try to explain the image they observed, using in a new situation the knowledge just gained.
10. ADVANCED LEVEL: the teacher sets up a challenge for individual students or groups on identification of gases in spectral lamps. Students need **to search for referent chemical elements spectra images in the internet.**

Coach's Advice

- It is very much important to gather as much context knowledge as possible during the brainstorming at the beginning of the implementation. It is a teacher's task to make sure that students recognize different light properties and phenomena in everyday life and they can distinguish them. During implementation of this unit students recall or learn the scientific expressions specific to different properties of light and phenomena related to light. The presentation leads the discussion.
- Depending on the class level, time that can be devoted for this activity and curriculum content, the teacher can ask students to investigate only different kinds of light sources, commonly available or, in addition, also the light emitted by spectral lamps. It is very much important for a teacher to monitor the final notes and make sure they are complete and consistent among all students in the classroom.
- The activity can be implemented in many curricula contexts, at different levels of advancement in physics. A simple guided IBL can be done, if the teacher introduces optics. More advanced scenario has been presented above. It is also possible to organize an open inquiry, in which the initial task is given not as a research question formulated (or quasi-formulated) by the teacher, but as a problem: Investigate light sources.

Coach's Learnings from implementation during a 3DIPhE workshops

If implemented during the PLCT workshops It is possible to introduce this learning unit even as the first experience of IBL, since it is spectacular and gives the idea of everyday materials being a rich resource for classroom lab work, especially in a distance learning mode.

Supplementary material

A worksheet for students is available in an editable form (.docx) and as a .pdf. The .pdf form fits to A4, to see the outlook of a booklet. This may change if its editable form is adapted to specific needs of a certain inquiry. The worksheet is accompanied by an instruction how to construct a spectroscope (.pdf)

3D_IBL_Worksheet_Rainbow in a box_UJ.docx;
3D_IBL_Worksheet_Rainbow in a box_UJ.pdf;
3D_IBL_Spectroscope_construction_UJ.pdf

A teacher guide for an IBL lesson using the poster and the worksheet is meant for a teacher and does not need printing if the teacher is used to reading on screen. Both forms, the .docx and .pdf are available. We also provide a presentation in editable format (.pptx)

3D_IBL_Guide_Rainbow in a box_UJ.docx;
3D_IBL_Guide_Rainbow in a box_UJ.pdf;
3D_IBL_Rainbow in a box_UJ.pptx

1.3.7

Speed

Eilish McLoughlin, IE

The unit was developed by Eilish McLoughlin from Dublin City University.

Context and goals

This unit was designed and implemented so that the teachers experience open and guided inquiry activities as learners. In this way it was hoped that they would have a better appreciation of what their own students experience was when doing IBL tasks. In addition, the coach selects one teacher to observe a pair of teachers carrying out open and guided inquiry investigations. This third teacher uses an assessment rubric to assess the pair of teachers' skills of planning investigations, identifying variables, collecting and interpreting data and working collaboratively. The third teacher shares their judgements on what inquiry skills had been evidenced by the teachers when carrying out both the Open and Guided Inquiry investigations.

GOAL	The Speed Unit provides teachers with several important experiences in IBL in which they plan and carry out guided and open inquiry activities.
IBL LEVEL	Guided and Open
AGE & SCHOOL TYPE	For all teachers of primary and secondary schools (all grades and levels)
GROUPING	Groups of 3 teachers, randomly chosen.
IBL unit resources	Adapted from Speed Unit which originated in the SAILS Project (http://sails-project.eu/units/speed.html). IBL and Assessment resources included in Appendix.
Key concepts	• Measurement (accuracy of measurements) of distance and time • Relationship between distance, time and speed.
Inquiry skills developed	• planning Investigations • collecting and interpreting data • drawing conclusions, • working collaboratively
Scientific reasoning	• Identification of variables • Making comparisons
Scientific literacy	• evaluate and design scientific investigation • scientific explanation of concepts (use of scientific expressions) • scientific explanation of phenomenon • understanding of physical quantities • presentation of scientific data (graphing) • understanding the real world context of the topic

Unit description

1. Introduction

- Teachers write out a plan (working individually) for two inquiry investigations:
  - Activity A: How fast can you go?
  - Activity B: how much time it takes you to walk 5 meters?
- Working in pairs, teachers swap their plans with another teacher and were provide feedback on their peer's plan. Teachers then update their own plans based on this feedback.

2. Carrying out Open Inquiry Investigation

- Teachers work in pairs to carry out their own plans for Activities A and B.
- A third teacher observes the pair of teachers and pays close attention to how closely teachers executed their own written plans. The third teacher notes any deviations from the written plans.
- The pair of teachers collate and share the findings of their inquiries while the third teacher highlights what deviations are made to the original plan.
- Feedback can highlight to the teachers the importance of writing accurate and careful plans for their inquiry to ensure the findings of their inquiry are repeatable, reliable and reproducible.
- Teachers reflect on their experience of planning and carrying out the Activities A and B.

3. Carrying out Guided Inquiry Investigation

- Teachers are asked to carry out two plans provided by the coach to address the same inquiry questions:
  - Activity A: How fast can you go?
  - Activity B: how much time it takes you to walk 5 metres?
- Teachers are again facilitated to work in pairs to carry out these plans while a third teacher observes their inquiry and notes any deviations from the written plan provided.
- The pair of teachers collate and share the findings of this second inquiry and compared their results to those obtained in the first inquiry.
- The third teacher in each group highlights what deviations (if any) had been made to the second plans.

4. Comparing Open and Guided Inquiry Investigations

- Teachers are given the opportunity to reflect on their experiences of carrying out the two activities according to their own plan and following the plan provided.
- Teachers are asked to consider the role of the teacher and learner in the first 'open' inquiry approach and the second 'guided' inquiry approach.

5. Assessing Inquiry Learning

- The third teacher in each group is provided with an assessment rubric provided by the coach that describes four-levels of success criteria for the inquiry skills (see Figure 1) of planning investigations, identifying variables, collecting and interpreting data and working collaboratively
- The third teacher shares their judgements on what inquiry skills had been evidenced by the teachers when carrying out both the Open and Guided Inquiry Investigations.
- All teachers reflect on what opportunities the learners had to develop skills or show evidence of learning in a guided inquiry versus an open inquiry.
- The rubric can be provided to all teachers and can be used for self- and peer-assessment.
- A second rubric can be used to self- or peer- assess inquiry skills for planning investigations as evidenced in the plans written by the teachers.

Assessment methods incorporated into IBL (if implemented or anticipated)

Formative: This unit uses the assessment methods of classroom dialogue, teacher observation, peer-assessment, self-assessment to collect evidence and make judgements on four inquiry skills - planning investigations, identifying variables, collecting and interpreting data and working collaboratively.

Summative: This unit uses worksheet Activities A and B to collect evidence and make judgement on the learner's understanding of the relationship between speed, distance and time and the relevance to everyday life. Learner's presentation of scientific data and their use and understanding of graphs to represent the relationship between variables is assessed in Activities C and D in the Worksheets.

Coach's Advice (for implementation in the classroom)

This unit is written to be carried out with teachers but it can be adapted for use with students in the classroom to address several goals, e.g. (i) develop student conceptual understanding of the relationship between speed, distance and time (ii) develop student understanding of the role of the teacher and student in open and guided inquiry and (ii) introduce students to the use of assessment rubrics for peer- and self- assessment.

This Unit is written Allow at least 100 minutes for the implementation of this unit. Activities may be carried out over several days but it is strongly advised that activities A and B are both carried out together and class discussion is facilitated directly afterwards.

Coach's Learnings from implementation during the 3DIPhE workshops

The teachers really engaged in planning and carrying out the activities of the Speed unit. There was lots of discussion comparing and contrasting guided and open inquiry approaches e.g. the role of the teacher and student, student confidence and enjoyment in following both approaches, what opportunities students have to develop skills or show evidence of learning in guided versus open inquiry approach. One teacher exclaimed, "that's a really good idea, I never would have thought of that". Indeed there was a lot of sharing of practice evident and teachers were discussing how the activity could be adapted for use in their lower second level science investigations.

Supplementary material

- Materials list: Measuring tape, Timer, Tape/Marker for floor
- Outline of Workshop on Speed Unit
- Worksheet for Speed Unit
- Assessment rubrics for Speed Unit

1.3.8

Spaghetti Bridge

Dagmara Sokołowska, PL

The tool was developed by Dagmara Sokołowska from Jagiellonian University, Krakow, Poland, Faculty of Physics, Astronomy and Applied Computer Sciences.

Context and goals

Manipulation with real materials, building construction from everyday materials is less and less addressed in curricula. This example is designed to fill the gap in a challenging manner with a show at the end, which is supposed to influence motivation and creativity of students or teachers.

GOAL	To build a construction with use of spaghetti noodle and participate in a show
IBL LEVEL	GUIDED at the beginning and OPEN during the challenge
AGE & SCHOOL TYPE	• Appropriate for any age 12-19 (limitation for the lowest age result only from safety rules) and for workshops with teachers
GROUPING	• preferably 2-3 students per group; it can also be done individually • depending on the teacher additional interest, groups can be formed by random or with special focus on gender or student ability composition • groups can be formed by a teacher or students themselves
IBL unit resources	Coach's original material
Key concepts	Equilibrium, center of mass, stability of constructions
Inquiry skills developed	• generating ideas in the discussion • design of a construction • working collaboratively, • presentation of the results
Scientific reasoning	• application of the acquired knowledge in a new situation • problem solving
Scientific literacy	• reviewing prior knowledge • understanding the real world context of the topic

Description of a tool and its use

Below the implementation of the unit is described in details in a chronological order. Parts of the description related to the Guide for teachers are marked in blue.

The activity takes ca. 1 lesson hour, but for younger students it can last a bit longer.
Materials for each group: one package of spaghetti noodle (500 g), hot glue gun and one or two glue sticks. One table per each group should be available, as well as a piece of cardboard to protect the surface of the table.

1. The IBL activity starts with **brainstorming** on any topic related to construction of stable structures. Depending on the age and the level of students that can go deeper into real building constructions or can be as simple as a discussion on supporting the center of mass in order to stabilize the construction. Pisa Tower example can be called, however it is not necessary. For older students even the recognition of the world-record buildings, bridges etc. can be checked. This activity should not last longer than 5-15 minutes. If time is available, the Spaghetti Bridge Championship can be described, students can hypothesize about the latest record and the possible shape of a bridge that enabled establishing that record. At the end the world record from 2009 can be shown: https://www.youtube.com/watch?v=_pejHjPJlcE. However for younger students all the latter part of the brainstorming can be omitted.

2. The ultimate goal of this IBL activity is to build a construction with use of a package of spaghetti noodles (500 g) and material to put the noodles together (e.g. a hot glue gun), and to participate at the end of the lesson together with other groups in a challenge set as the following: the construction is supposed to prop one can of any soda drink (330 ml) for at least 90 s. The show of all constructions is done at the same moment.

3. The groups first **generate ideas**, **choose the right material** for sticking the noodles, **discuss in groups the physical rules** they need to follow, **decide on the form of a construction, design a construction** while **working collaboratively** (altogether ca. 30-40 minutes). At the end all groups present their construction in a show (ca. 5 minutes) and at the end a short summary can be provided by the teacher or, if time is available, by representatives of each group.

4. After the show students reflect individually on two questions:

   A) What was/were the most successful construction(s)? List the factors which, in your opinion, made this construction so good in fulfilling the task.

   B) What was/were the least successful construction(s)? What were the problems, which did not enable the constructors to fulfil the task?

   and **take notes**.

Assessment methods incorporated into IBL

Formative assessment: self- and peer-assessment on collaboration after completing the challenge; rubrics on specific aspects of the activity of designing or building a construction (prepared by the teacher in advance).

Coach's Advice

- It is very much important to gather as much context knowledge as possible during the brainstorming at the beginning of the implementation. It is a teacher's task to make sure that students recognize main phenomena and principles of construction of buildings (center of mass, equilibrium).
- It is possible to give the students freedom in a choice of the material that serves for putting construction together (hot glue, tape, paperclips etc.), however such an approach may lead to a very quick and trivial solution of taping all spaghetti noodles in order to form a bunch. Since such a solution is not very much creative, it is recommended at least to forbid the use of tape.

Coach's Learnings from implementation during a 3DIPhE workshops

If implemented during the PLCT workshops It is possible to introduce this learning unit even as the first or second experience of IBL, since it is spectacular and gives the idea of everyday materials being a rich resource for classroom lab work, especially in a distance learning mode.

Supporting material

A worksheet for students is available in an editable form and as a pdf. The pdf form fits to A4, to see the outlook of a booklet. This may change if its editable form is adapted to specific needs of a certain inquiry.

3D_IBL_Worksheet_Spaghetti Bridge_UJ.docx;
3D_IBL_Worksheet_Spaghetti Bridge_UJ.pdf;

A teacher guide for an IBL lesson using the poster and the worksheet is meant for a teacher and does not need printing if the teacher is used to reading on screen. Both forms, the .docx and .pdf are available. We also provide a presentation in editable format (.pptx)

3D_IBL_Guide_Spaghetti Bridge_UJ.docx;
3D_IBL_Guide_Spaghetti Bridge_UJ.pdf;
3D_IBL_Spaghetti Bridge_UJ.pptx;

1.3.9

Subtle Shifts

Jan De Lange, BE

Context and goals

The unit was described & tested by Jan De Lange from Artevelde University College in the 3DIPhE project, but all credits go to the Exploratorium and the Institute of Inquiry.

Important note: *This is an activity for teachers and is not meant for students, so goals & activities are described for teachers. However we notice that teachers are copying and adapting some of the activities (on chemical reactions and shadows) in the context of their classroom.*

GOAL	• To help teachers recognize that students need to be given more responsibility for aspects of their own learning in order to develop science process skills necessary for inquiry. • To help teachers recognize that they can prepare students for doing inquiry by making small changes in activities they already do.
IBL LEVEL	From structured to more open inquiry
AGE & SCHOOL TYPE	For all teachers of secondary schools (all grades and levels)
GROUPING	Groups of 2 teachers, randomly chosen.
IBL unit resources	This activity uses 2 examples: chemical reactions and shadows. All credits go to the Exploratorium and the Institute of Inquiry. Permission for use of these materials is granted for noncommercial educational purposes. Users who wish to duplicate these materials must ensure that the Exploratorium Institute for Inquiry is properly credited, and the original copyright notice must be included. You can download the full copy of this guide at www.exploratorium.edu/ifi/subtleshifts
Key concepts	Key science concepts developed in the example of • Chemical change: chemicals, chemical reaction, indicators for chemical change • Measuring shadows: light source, shadow, propagation of light
Inquiry skills developed	• Planning investigation • Developing hypothesis, • Forming coherent arguments, • Data gathering skills • Drawing conclusions
Scientific reasoning	• Identification of variables, • Making comparisons
Scientific literacy	• Evaluate and design scientific investigation

Unit description

*The course of implementation during 3DIPhE: these activities are done by teachers (**as learners**). Teachers will first experience an IBL unit on chemical change that is slightly shifted and more open (**learning by experiencing**) and compare it to the original unshifted and structured unit. In this way they come to certain important learnings (learn **by reflecting**). Eventually they will apply these learnings and try to shift some of their own IBL units (**learning by doing**).*

1. Doing a "Shifted" IBL activity on chemical change (learning by experiencing)
   Instructions for teachers:
   - Choose a partner to work with.
   - Safety first: do not eat or smell at the chemical substances.
   - Now investigate following the worksheet 'shifted activity'.
     - Key question: "What indicates the occurrence of a chemical change?"
     - Part I: exploration (focus on careful observation & **data gathering skills** using a data-collection sheet).
     - Part II: 2nd exploration giving more ownership more choice about the experimental procedure (**planning investigations, developing hypothesis**)
     - Summarize (**forming coherent arguments, drawing conclusions**)
       - Analyze and summarize the results of experiments on data-collection sheets.
       - Describe what you have discovered about chemical change.
   - Find another group and discuss conclusions and answers related to the key question. (**forming coherent arguments, drawing conclusions**)
   - Discuss with whole group:
     - Was there a chemical change?
     - How certain are you?

     It's hard to be sure if a chemical reaction has taken place if you only observe one sign. But several signs, as we observed in this activity, are fairly strong evidence.

     For the facilitator see list of materials for doing this activity and some background science.

2. Discuss and degree of teacher-learner responsibility (learning by reflecting)
   - In groups teachers think about the responsibility of the students and teachers during the IBL unit. They can use the worksheet responsibility.
   - Discuss with the whole group & listen to arguments.

3. Comparing Shifted and Unshifted Activities (learning by reflecting)
   *The instructions in this worksheet have been "shifted" from the original. More directive worksheet to give the students more choice about **experimental procedure** and more responsibility for **determining results**.*
   - Look at the worksheet unshifted activity and write down in group what shifts have been made in the shifted activity that teachers have done first.
   - Discuss with the whole group and summarize. Possible teacher-identified shifts are:
     - Language of instruction is more open-ended.
     - Students design their own data sheets.
     - Students choose what they investigate.
     - Students are asked to report what they think is significant.
     - There's no assumption that there's a "right" answer.
     - There's an expectation that learners will have new questions when they're finished.

- Discuss in the whole group what are the benefits of making these small changes. Possible teacher-identified benefits of shits are:
  - Designing their own data sheets gives students a sense of freedom and also helps them focus.
  - Because students aren't told what to look for, they have to observe and interpret their results very carefully.
  - Students have to use higher-order thinking skills to interpret and analyze what they are seeing.
  - Students have to describe in detail what they observe, then analyze and summarize what they did very carefully.
  - To explain their results, students have to write more than just brief notes.
  - Students have ownership of what they do.
  - Students are encouraged to make discoveries.
  - It's empowering to make your own discoveries.
  - Having choices gives students confidence.
  - Students have to think for themselves.
  - Anticipating what results they might get keeps students involved.

4. Elaborating on learning using a new example 'measuring shadows'. The worksheet on shadows shows two shifted units and the original unshifted unit.

5. Making shifts with your own units. (learning by doing)
   - In groups of 2 participants are reading through each other units and discussing what small changes can be made to these units.
   - Small changes can be presented to the whole group and discussed.

Assessment methods incorporated into IBL

Formative: during group discussion and dialogue all participants are reflecting about what they have learned (e.g. a tool for classroom dialogue can be used).

Coach's Advice (for implementation during coaching of teachers) and coach's Learnings from implementation during the 3DIPhE workshops

- Step 4 is optional when teachers need another example from a different subject (physics example).
- Step 5 is very powerful because participants will apply the learning from the first activities into their own practice. However, in the case of PI-IBL courses they may not have sufficient time to do the whole activity.
- This activity is a very good start to guide participants towards an inquiry question during their Practitioner Inquiry in the context of IBL. It is very specific and feasible to use it in their own practice because it is dealing with small changes. However, in the 3DIPhE course, teachers did not use these subtle shifts in their PI, but they have said that after this activity they easily made some small changes in their instructions and worksheet of students' practical work. So they actually implemented it, but did not use it as a topic for their PI. You should give this ownership to the teachers and let them decide by themselves.

Supplementary material

- Worksheet shifted activity
- Materials for chemistry activity
- Background science for chemistry activity
- Worksheet responsibility student teacher
- Worksheet unshifted activity
- Worksheet on shadows

1.3.10

Which chocolate is the best?

Ana Gostinčar Blagotinšek, SI

The unit was developed by Ana Gostinčar Blagotinšek, from University of Ljubljana, Faculty of Education, Slovenia.

Context and goals

Inquiry about the chocolate melting temperature is motivating, as it is dealing with a popular everyday snack. It is a highly structured and guided unit, suitable for beginners (teachers and students) in IBL. Suggested steps of inquiry are specified in continuation. Although simple, its surprising findings give a taste of real research. The unit can be used either to improve IBL skills, exploring properties of matter, or studying temperature and heat transfer. The experiment is shown in Fig. 1

GOAL	• to train/improve the observation skills • to encourage predictions • to design testing experiments • to draw conclusions • to study melting point (temperature)
IBL LEVEL	Structured inquiry
AGE & SCHOOL TYPE	Appropriate for all levels; as inquiry exercise also for primary, as motivation activity also for university/adults
GROUPING	• randomly formed groups of 3-4 students with respect to ability, gender and friendship by drawing cards; • *classroom space arrangement: nests* (2 desks for two persons together)
Key concepts	Temperature, melting point (temperature)
Inquiry skills developed	• elaborating research questions • planning investigation • working collaboratively • articulating predictions • designing testing experiments • presentation of the results • drawing conclusions and interpretation
Scientific reasoning	• identification of variables • making scientific connections • making comparisons • transfer of learnings in a new context
Scientific literacy	• evaluation of the content of food • evaluate and design scientific investigation • scientific explanation of concepts (use of scientific expressions) • understanding the real world context of the topic • fair test

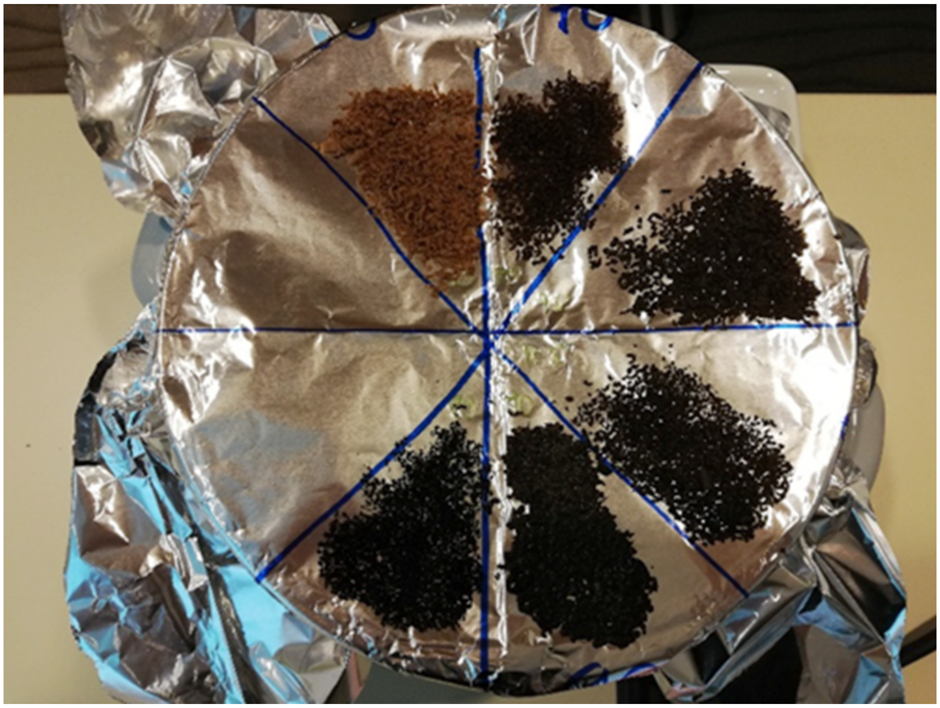


Figure 1. Heating grated chocolate samples over warm water.

Unit description

1. Introduction

Lesson starts with a broad question about what is "the best" – making students realize that very different criteria apply for different persons and occasions. Narrowing the scope and focusing on a precise problem of melting chocolate in warm surroundings makes it a real-life problem, already experienced by nearly everyone: chocolate snacks are prone to melt in pockets and bags and make a mess. This makes the topic motivating, relevant and connected to everyday life.

2. Identifying possible (independent) variable(s)

Chocolates are different in many aspects; students usually focus on energy value, added ingredients (nuts, rice, …) or cocoa content.

3. Identifying possible (dependent) variable(s)

How "quickly" the chocolate melts can be evaluated either in terms of time needed for melting or melting temperature.

4. Choosing independent variable

Cocoa proportion is often clearly stated on the packaging and is available in broad spectra – from approx. 30 % to 99 % at least in some brands. This makes planning the inquiry and controlling the independent variable simple and does not require additional knowledge or skills.

5. Choosing dependent variable

We suggest choosing melting temperature. Measuring the required time (at constant temperature) is also an option.

6. Listing constants/controlled variables

All variables, listed in Step 2, should be monitored and not changed at all (if this is not possible, they should change as little as possible) – except our chosen independent variable (listed in Step 4). This stage needs commenting on proportions of all ingredients being interdependent. More cocoa obviously means less milk, sugar etc. and does not make the inquiry unfair.

7. Forming the inquiry question

The form to help students form the appropriate question is supplied. Others are also possible.

8. Forming the prediction/hypothesis, educated guess

Forming the prediction/hypothesis about the outcome of the inquiry and justifying their statements should focus students on the inquiry question and help them reflect on what they already know or have experience with – related to the current problem. It is not important whether the hypothesis is correct.

9. Planning the inquiry

a) What we plan to do and how?

b) What do we need (list of experimental equipment and other tools)?

c) Which data will be collected? How will we record it?

Additional questions are meant as a scaffolding for the students.

Equipment per group (optional items for alternative inquiry about time, needed for melting):

- Chocolates (preferably of the same brand) with different percentage of cocoa,
- Aluminum foil,
- Electric stove/cooker,
- Dish (diameter approx. 20 cm),
- Thermometer,
- Paper trays (for chocolate samples),
- Grater (to grate samples of chocolate),
- Stopwatch (optional),
- Coins or metal paperclips (optional).

The same brand of chocolates should be purchased and grated in advance for beginners in IBL; if the teacher wants to focus on fair testing, he/she might leave the decision on brand, size and shape of the samples to students and only provide a variety of samples.

The temperature of the chocolate is difficult to measure directly and it is better to place the chocolate samples on aluminum foil, which is stretched over the container with water, or it floats directly on the water. The chocolate particles should be spread on the foil in a thin layer, otherwise those in contact with the foil are not visible at all (Fig. 1). The temperature of the water should increase gradually, by heating on the stove, and the temperature of the water and the condition of the chocolate crumbs should be monitored frequently.

If the aluminum foil is stretched over a container of water, the chocolate samples should be arranged in a ring along the brim of the container - heat flows along the metal walls of the container, which heat up more than the water in it. Therefore, samples that are closer to the brim of the container (regardless of the cocoa content) are melted first. In physics lessons, the details of the heat transfer and its impact, and interpretation of (conflicting) results can also be left to the students.

If students decide to measure the time in which the chocolate melts (at, for example, 35 ^{0}C) in the inquiry, they should think carefully about how to objectively decide whether the sample is already melted. The already melted chocolate usually maintains the shape even above the melting temperature if left untouched. One of the possibilities is, for example, loading samples (pieces of chocolate) with (identical) coins or metal paperclips; when a coin / paperclip sinks into a piece of chocolate, it is molten.

Data about melting temperatures should be recorded in a table.

10. Conducting the inquiry and interpretation of the results

This inquiry is very structured; students should be prompted to stick to their plans or record any necessary changes. The recording of the observations/measurements should be encouraged. The results should not be reported in form of confirming/rebuffing the hypothesis; it should be the answer to the inquiry question in a full sentence. Results usually surprise students, as samples with higher percentages of cocoa are harder to the touch but melt at lower temperatures/first.

11. Conclusions and presentations of inquiry; relevance for the initial problem

Reporting results can be done in the form of "The smaller/bigger the percentage of cocoa, the higher/lower is the temperature of melting". Other ingredients might influence the results, so this is just a detected trend and results might be inconclusive.

12. UPGRADE to more demanding inquiries (optional)

Temperature distribution on the aluminium foil can be studied and visualized with an IR camera or measured with an IR thermometer.
Others might inquire about the impact of brands; they use different types of fats, additives etc., which might also influence the melting temperature.
Another possibility is to apply the gained knowledge to design mess-free packaging or to make chocolate sweets.

Coach's Advice for implementation in the classroom

Some safety considerations are recommended: danger of burns with hot water and checking for students with allergies (nuts, milk …). Grating of samples also proved dangerous – students might suffer cuts to their fingers. All equipment and hands should be kept clean and sanitary, as students love to eat leftovers.

For a successful experiment the water should be at room temperature at the beginning and heated slowly, otherwise the melting might be almost simultaneous. Some sort of objective testing when the samples are melted, should be planned as discussed in Step 9.

Coach's Learnings from implementation during the 3DIPhE workshops

The activity was tested with the Slovenian group of teachers, who find it useful for the motivation of students and also educational; the result is surprising despite nearly everybody having an experience and a strong "knowledge" about the phenomenon.

Supplementary material

The worksheet for students is found under name 3D_IBL Worksheet_Chocolate_UL.pdf,
and in its editable form 3D_IBL Worksheet_Chocolate_UL.docx.

The guide for a teacher is found under name 3D_IBL Guide_Chocolate_UL.pdf,
and in its editable form, which allows for copying pictures, modifications and notes for later use is 3D_IBL Guide_Chocolate_UL.docx.

The teacher may use a large (A0 size) printed poster attached to the whiteboard, and/or students can have small A4 versions of the same poster on their desks as reminders of important steps. The poster is found as 3D_IBL_Poster_Inquiry guide_UL.pdf.

Generic template for the IBL unit

Ana Gostinčar Blagotinšek, Maja Pečar and Mojca Čepič, SI

IBL accompaniment tool: generic poster, worksheet and guide

The tool was developed by Ana Gostinčar Blagotinšek, Maja Pečar and Mojca Čepič, from university of Ljubljana, Faculty of Education.

Context and goals

The tool helps the teacher, who is a beginner in the inquiry based learning, to effectively plan and carry out an IBL lesson. Worksheets for students encourage conscious planning and other actions needed in inquiry and systematic inquiry notes.

GOAL	Tools supporting teachers and their students through activities introducing IBL
IBL LEVEL	Tools are appropriate for all levels of inquiry, however, they are relatively easy to adapt for a specific structured or guided inquiry, but for open inquiries can serve more as guidance or suggestions.
AGE & SCHOOL TYPE	Any; for younger students some of the text in a worksheet for students could be left out or rearticulated to more simple expressions.
GROUPING	The worksheet can be filled in by the whole group but in this case the teacher has to be very careful that all students have institutionalized notes in their notebooks including important sketches, tables, graphs etc. Alternatively, each member of a group takes care for her/his notes in the worksheet during the process. The teacher encourages extensive records, but nevertheless, final conclusions have to be articulated by students and the teacher together and the teacher has to control that all students have those "institutionalized" conclusions recorded in their notes.
IBL unit resources	Helen Buttemer (2006), Science on board. Science and Children, Vol. 44, No. 2. 34-39.
Key concepts	independent, dependent and control variables, fair test, planning experiments, drawing conclusions, reporting
Inquiry skills developed	Choosing variables, forming an inquiry question and predicting an answer, planning an experiment, collecting and presenting data/measurements, drawing conclusions, formulating an answer to inquiry questions supported by data, and reporting findings, everything in a well sequenced and systematic way.
Scientific reasoning	See above.
Scientific literacy	See above.

Description of a tool and its use

1. What does this tool include?

The tool includes three components editable/printable form:

- The poster called Inquiry guide (3D_IBL_poster_Inquiry guide_UL.pdf);
- A generic form of a worksheet for students (3D_IBL_Worksheet_Generic for students_UL.docx/pdf);
- A generic guide for an IBL lesson using the poster and the worksheet (3D_IBL_Guide_Generic for teachers_UL.docx/pdf).

2. The poster: Inquiry guide

The poster helps the teacher to resume and discuss decisions after every step in the process of finding and choosing relevant variables and forming an inquiry question.

The poster is printed into a large A0 size and is attached to the whiteboard, if the teacher decides to guide the inquiry based unit more actively. Stickers with variables are attached to specified boxes and are visible to all students in the classroom.

Smaller versions of a poster (A3 or A4) can be printed as supporting materials for groups. Each group gets one poster and can use it for evidence of variables and to discuss the choice of independent, dependent and control variables. If students are already experienced, the small version of the poster can serve as a reminder and the large version is not needed anymore or it is used during the final presentation only.

3. Generic worksheet for students

The worksheet is structured stepwise similarly to the poster, but it covers the whole inquiry to the very end, when students report their findings and record institutionalized conclusions. The worksheet is available in an editable form and the teacher is advised to adapt/tailor the worksheet to specifics of the planned inquiry. The worksheet has 5 pages, from which the first four cover the structured or guided inquiry and the last page is available for potential extensions. If no extensions are planned, the first four pages are printed in a "book" printed mode double sided to A3 paper and folded in the middle to get an outlook of a booklet. The fifth page can be given to fast or more able groups separately, when the group fills in all the boxes in the booklet.

Two modes of using the worksheets are possible. Each group of students gets one worksheet and they collaboratively record their inquiry. This mode of inquiry is faster, but on the other hand, the teacher has to take care that all students write in their personal subject notebooks all the important facts regarding inquiry: the problem, variables, comments on the variables, inquiry questions the planning of experiment, collected data, conclusions and the answer to inquiry questions supported by reasoning and data. Students like to avoid the writing quite often.

The second possibility is that each student has her/his own worksheet, each student makes her/his own notes, but the group prepares the report and the final presentation of findings together.

4. Generic Guide for teachers

The teacher, beginner in preparation of IBL lessons may use this guide as a help in her/his first steps to IBL world. The guide has the same form as a student's worksheet, only suggestions how to guide the lesson, which traps would be good to avoid, where the teacher should stop and reflect, how to effectively guide students through a labyrinth of variables etc. are added and discussed. The guide is available in an editable form, which allows the teacher to add comments before or after the lesson or to adapt the guide to a specific inquiry, to include pictures, sketches, photos, to plan assessment etc. This guide can also be used for reflection on a lesson, as documented work of students can be included and can serve as data collection in a practitioner inquiry of a lesson.

Coach's Advice

Three documents that form together this tool could be used in various ways.

If students and the teacher are all beginners, we advise using the large poster attached to the board, and one small poster and one worksheet for each group. Students should make notes in their notebooks and make a copy of the final filled in worksheet. The teacher is advised to use the guide during her/his preparation and to play a role of a student, that is, to think aloud about variables, to carry out experiments and exemplary fills in the whole worksheet. The teacher may also use already adapted worksheets and guides on the problem of melting temperature of a chocolate, pressure or penumbra.

If students are not yet experienced and the teacher is, the teacher may consult the guide only if she/he is unsure on some of the points. But for students the same method as above is used. If students have carried out at least one inquiry already, each student gets her/his own worksheet and the teacher takes care that all students fill in the worksheets.

Finally, if students are already experienced, each group has a small poster as a reminder on steps in the process, but the large poster is not needed anymore. Students should still use worksheets for recording their activities.

Coach's Learnings from implementation during the 3DIPhE workshops

The poster was adapted from the poster that was designed in FP7 project FIBONACCI. Reflections on activities where it was used, lead to a slightly different organization of boxes and rephrasing some of the subtitles. The changes reflect the fact that introduction to the inquiry problem was not included in the poster and that a good inquiry question can be formed after variables are discussed.

During IBL activities with both Slovenian professional learning communities (PLC), some steps in inquiry were sometimes skipped, some have taken too much time etc. Therefore we constructed a generic worksheet that was later adapted to specific examples. The members of our PLCs loved them and widely used them for activities in their classes and filled in worksheets were included as data for their practitioners' inquiries.

However, suggestions of inquiries came from Slovenian partners. Participants, members of PLCs used worksheets that were accompanied by discussion and instructions of coaches. Without such discussion both, the poster and the worksheet, are not so useful that they could be. The experience of the coaching stimulated us to add detailed information regarding teachers' activity during IBL to the boxes as a guide.

Supplementary material

The poster is available in a pdf form only as it was designed in a professional program.
3D_IBL_Poster_Inquiry guide_UL.pdf

A generic form of a worksheet for students is available in an editable form and as a pdf. The pdf form fits to A4, to see the outlook of a booklet. This may change if its editable form is adapted to specific needs of a certain inquiry.

3D_IBL_Worksheet_Generic for students_UL.docx
3D_IBL_Worksheet_Generic for students_UL.pdf

A generic guide for an IBL lesson using the poster and the worksheet is meant for a teacher and does not need printing if the teacher is used to reading on screen. Both forms, the docx and pdf are available.

3D_IBL_Guide_Generic for teachers_UL.docx
3D_IBL_Guide_Generic for teachers_UL.pdf

CHAPTER 2:
Best IBL Practices by Teachers

2.1 INTRODUCTION

Teachers - PLCT members participated in two iterations of workshops provided by coaches, the members of the 3DIPhE consortium. During every workshop some time was devoted to the development of teachers' skills in conducting lessons with use of the IBL method. Teachers participated in activities experiencing the spirit of the method and different approaches to different steps of the IBL cycle of work. During the workshops a lot of exemplary units (see part 2. chapter 1) were thoroughly elaborated in order to prepare teachers for the future work on development of their own materials.

Teachers preparing their Practitioner Inquiry focused on several different aspects of students' work in the IBL cycle (different skills developed during particular parts of the IBL cycle, grouping structure and procedure and their influence on the learning outcomes or students' attitudes and motivation towards subjects etc.). For the purpose of the Practitioner Inquiry each teacher chose a curriculum topic, designed his/her own IBL unit or adapted the unit found in the external resources, and implemented the IBL materials in their classes. Teachers worked with different students at different IBL levels, depending on their own situation and students' learning goals specific to the particular curricula. This way a collection of IBL practices was gathered, among which a set of the best practices was identified. We present them in the next section.

Since the collection can be regarded as a set of teachers' testimonies, based on their own experience, we believe it is very authentic and thus will be valuable for other teachers planning implementation of the IBL method and/or thinking about doing the Practitioner Inquiry in their IBL classes. The set of the practices comprises a variety of topics and aspects, thus every teacher can find here examples he or she can relate to. A very valuable part of each PLCT best example is a subsection Teacher's Learning in which teachers provide their perception of the unit implementation, based on their practice.

2.2 COLLECTION OF THE BEST IBL PRACTICES IMPLEMENTED BY TEACHERS

The list of the best IBL practices implemented by PLCT teachers during their Practitioner Inquiry consists of 17 examples developed in four countries: Belgium (BE), Ireland (IE), Poland (PL) and Slovenia (SI), see Table 2.1.

No.	IBL modul title	Author(s)	Country
1.	Alcoholic Fermentation	Carine Vallons	BE
2.	Balance of forces and use of trigonometric functions	Špela Gec Rožman & Špela Povše Pistotnik	SI
3.	Cooler Bag	Barbara Jančič	SI
4.	Density	Anna Bekas	PL
5.	Determining Taste Zones of the Tongue	Guy Puttevils	BE
6.	Earth and Space	Caroline Quirke	IE
7.	Eco-travelling	Rita Deraedt	BE
8.	Electrical Circuits	Renata Szyndak	PL
9.	Electricity	Seán Kelleher	IE
10.	Exploring the Perimeter and the Area of Complex Objects	Simona Verdinek Špenger	SI
11.	Gravitation, Weight & Centrifugal Force	Beata Świder	PL
12.	Leaking bottle: which water jet is the longest?	Uroš Medar	SI
13.	Measurement in Physics	Fiona Kelly	IE
14.	Moon – Earth's companion	Małgorzata Szymura	PL
15.	Paper Planes	Arne Van Assche	BE
16.	Spectroscope	Beata Sobocińska	PL
17.	Synthesize the Timbre of Your Preferred Instrument	Jordy Zwaenepoel & Tessa Jacobs	BE

Table 2.1. Teacher's best practices of IBL implementation.

Each implementation is described by a teacher in a compact document, giving information about the IBL level, age of the students and the type of the school, grouping, IBL resources and the key concepts introduced, discussed and inquired during the lesson. Teachers identified also the inquiry skills developed during the implementation, as well as scientific reasoning skills and scientific literacy aspects developed through inquiry. The document presents Unit description, Relation between PI and IBL, as well as a section on Teacher's Learning in which the authors share their observations and opinions about the implementation. Most of the practices are based on teachers' own ideas and materials, designed for the purpose of a particular topic in the curricula. In a few cases, when the IBL unit was designed with use of the existing material, the link to the original material is provided.

The collection is quite diverse with respect to the subject (physics, science, math, chemistry and biology), students' age (10-19), students' grouping structure (two, three, four or five students per group) and grouping procedure (group selection by a teacher or students; grouping by abilities, gender or at random with respect of any of them), as well as the IBL level (structured, guided, open), compare with Table 2.3 (abbreviations explained in Table 2.2). Most of the teachers used assessment tools, either formative (six examples), summative (one example) or both, formative and summative (eight examples) during and/or after the implementation, as indicated in Table 2.3. Only two teachers did not report any assessment strategy linked to the IBL implementation.

category	abbr.	explanation
IBL level	S	structured IBL
	G	guided IBL
	O	open IBL
Subject	Ph	physics
	M	math
	S	science
	B	biology
	Ch	chemistry
	Mu	music
	T	technology
Curriculum	C	
	SC	standard curriculum (the same for all at this age)
	BC	basic curriculum
	AC	advanced curriculum
	SEN	Special Education Needs curriculum
Group formation	T	by teacher
	S	by students
	ATS	as they sit
Ability specific grouping	ASG	
Gender specific grouping	GSG	
	R	at random
	IM	intentionally mixed-gender or mixed-ability
	MS	male school
Assessment	A	
	FA	implementation of formative Assessment
	SA	implementation of summative assessment
Supplementary material available	SM	
	W	worksheets
	T	tests
	L	a link to the original material is provided

Table 2.2. Abbreviations used in Table 2.3

No.	IBL module title	IBL level	Subject	Age	C	Students per group	Group generator	ASG	GSG	A	SM
1.	Alcoholic Fermentation	O/G	Ch/S	17	AC	2	-	-	-	F	L
2.	Balance of forces and use of trigonometric functions	G	Ph/M	15-16	-	4	T	IM	MS	-	-
3.	Cooler Bag	G/O	T/S	10	-	2-3	S	R	R	-	-
4.	Density	G	Ph	13	SC	4	ATS	R	R	F&S	-
5.	Determining Taste Zones of the Tongue	G	B	14	SC	3	-	-	-	F&S	W
6.	Earth and Space	G	B/S	14	-	3	T	R	MS	F&S	-
7.	Eco-travelling	G	Ch	16	-	4	-	-	-	F&S	L
8.	Electrical Circuits	G	Ph	18-19	AC	3 or 4	1.S, 2.T	R	R	F	-
9.	Electricity	G	S	15	-	4	S	R	MS	F&S	W&T
10.	Exploring the Perimeter and the Area of Complex Objects	G	M	11	SC	4	S	IM	R	F	-
11.	Gravitation, Weight & Centrifugal Force	S	Ph	16	BC	5	S	R	R	F&S	-
12.	Leaking bottle: which water jet is the longest?	O	Ph	13	SC	4-5	S	R	R	S	-
13.	Measurement in Physics	G	S/Ph	13-14	SEN	2 or 4	T	IM	-	F	W
14.	Moon – Earth's companion	S/G	Ph	16	BC	3	S	R	R	F&S	W
15.	Paper Planes	S/G	Ph/S	12	SC	3	-	-	-	F	W
16.	Spectroscope	S/G	Ph/S	16	BC	4	S	R	IM	F	L
17.	Synthesize the Timbre of Your Preferred Instrument	G	Ph/Mu	14-16	-	3	T	R	R	F&S	-

Table 2.3. Summary of general information about the best practices developed by teachers during the IBL lessons (abbreviations explained in Table 2.2)

Teachers' examples represent a good diversity of topics and subjects. Only five examples are solely physics examples, three others are related to topics from physics and/or science curricula with physics elements. One example lies on the edge of physics and math, another one - on physics in combination with music. Chemistry and/or science topics on chemistry are tackled in two examples. Two other examples relate to biology or a combination of biological and chemical lessons. One implementation starts during the technology lesson and continues over a science lesson.

Most of the material provided by teachers is related to guided IBL, although one example is designed in the structured IBL and three others are partially structured, partially guided. Two examples are based on a combination of a guided and open instruction, and yet another is solely open. Half of the material is designed for a standard curriculum in primary or lower secondary classes (including one focusing particularly on students with special needs), the other half is designed for upper secondary schools (basic or advanced level, or not specified).

In most IBL designs students worked in groups of 3 or 4, with two exceptions for grouping by 4-5 or 5 and two exceptions of working in pairs. During the reported implementations either the students or the teachers were responsible for selection of students into groups and only in one case the strategy of grouping "as they sit" was reported. As regarding the division into ability groups, in most cases it was done on random and only in three implementations the groups were formed intentionally as mixed-ability groups. Only in one example the mixed-gender groups were formed intentionally by the teacher, in all others implementation in co-education classes, the selection was done regardless the gender of students.

Additionally to the short reports, almost half of the teachers provided also additional material, such as worksheets or tests, or at least a link to the unit resource or the material they were inspired by.
On the basis of the IBL units descriptions provided by teachers, three lists of: (A) IBL skills, (B) scientific reasoning skills and (C) scientific literacy aspects were identified as addressed by teachers in their IBL implementations. We present them in Table 2.4.

ID	IBL skills	ID	Scientific reasoning skills	ID	Scientific literacy acquirements
A1	generating ideas in discussion	B1	identification of variables	C1	reviewing prior knowledge
A2	elaborating research questions	B2	classifications	C2	understanding the properties of physical/ chemical/biological quantities
A3	developing hypotheses	B3	making scientific connections	C3	evaluate and design scientific investigation
A4	planning investigation	B4	proportional and/or inversely proportional reasoning	C4	identifying consequences of humans' intervention in the environment
A5	forming coherent arguments	B5	application of acquired knowledge in a new situation	C5	presentation of scientific data (graphs, tables)
A6	working collaboratively	B6	choosing right components (materials, devices)	C6	scientific explanation of concepts (use of scientific expressions)
A7	data gathering skills	B7	problem solving	C7	evaluation of the content (e.g. food, substances)
A8	data analysis skills	B8	making comparisons	C8	critiquing a method
A9	drawing conclusions			C9	searching for information in external sources
A10	presentation of the results			C10	scientific explanation of phenomena
				C11	understanding of physical quantities
				C12	modelling physical quantities or phenomena
				C13	understanding the real world context of the topic
				C14	fair test

Table 2.4. The list of inquiry skills, scientific reasoning skills and scientific literacy aspects developed in students during implementation of teachers' IBL units.

These lists served as sets of indicators characterizing the particular IBL units designed by teachers. Below, all best IBL practices are listed and related to IBL skills (Table 2.5), scientific reasoning skills (Table 2.6) and scientific literacy aspects (Table 2.7) developed in students.

No.	IBL modul title	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
1.	Alcoholic Fermentation	✓	✓	✓	✓	✓	✓				✓
2.	Balance of forces and use of trigonometric functions			✓		✓	✓			✓	✓
3.	Cooler Bag			✓	✓	✓	✓	✓	✓		✓
4.	Density			✓	✓		✓	✓		✓	✓
5.	Determining Taste Zones of the Tongue	✓	✓		✓		✓	✓		✓	
6.	Earth and Space			✓	✓	✓		✓	✓	✓	
7.	Eco-travelling	✓		✓	✓	✓	✓			✓	✓
8.	Electrical Circuits			✓	✓	✓	✓			✓	
9.	Electricity	✓		✓							
10.	Exploring the Perimeter and the Area of Complex Objects			✓				✓		✓	
11.	Gravitation, Weight & Centrifugal Force			✓	✓	✓	✓			✓	
12.	Leaking bottle: which water jet is the longest?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
13.	Measurement in Physics	✓			✓		✓	✓			
14.	Moon – Earth's companion			✓	✓	✓	✓	✓	✓	✓	✓
15.	Paper Planes	✓					✓	✓		✓	
16.	Spectroscope			✓	✓	✓	✓	✓	✓	✓	✓
17.	Synthesize the Timbre of Your Preferred Instrument			✓	✓	✓	✓		✓	✓	✓

Table 2.5. IBL skills identified by PLCT teachers as skills developed in students during the implementation of the particular IBL units.

Since most of the PLCT teachers implemented the guided IBL, in the vast majority of examples the development of the IBL skills, such as developing hypotheses, planning investigation, working collaboratively and drawing conclusions is reported. In most of the implementations teachers devoted at least some time to forming coherent arguments, mostly during the discussions on the forum of the entire class. In a similar number of implementations some time was also devoted to data gathering and presentation of the results. Less than half of the teachers reported focusing on generating ideas in discussions. Elaboration of research questions and data analysis are least represented in the material provided by PLCT teachers. For details, refer to Table 2.5.

As regarding scientific reasoning skills, most examples focus on identification of variables, making scientific connections, problem solving and making comparisons. In less than half of implementations students were asked to choose by themselves the right components (materials, devices) for carrying out the experiments. Classifications, application of acquired knowledge in a new situation, as well as proportional/or inversely proportional reasoning are reported only in sparse cases (compare: Table 2.6).

No.	IBL modul title	B1	B2	B3	B4	B5	B6	B7	B8
1.	Alcoholic Fermentation	✓					✓		
2.	Balance of forces and use of trigonometric functions	✓		✓				✓	✓
3.	Cooler Bag	✓						✓	✓
4.	Density	✓		✓	✓				
5.	Determining Taste Zones of the Tongue	✓					✓	✓	✓
6.	Earth and Space	✓		✓					
7.	Eco-travelling							✓	✓
8.	Electrical Circuits			✓				✓	✓
9.	Electricity			✓				✓	
10.	Exploring the Perimeter and the Area of Complex Objects			✓		✓		✓	✓
11.	Gravitation, Weight & Centrifugal Force	✓		✓			✓	✓	✓
12.	Leaking bottle: which water jet is the longest?	✓						✓	✓
13.	Measurement in Physics		✓				✓		
14.	Moon – Earth's companion	✓		✓				✓	✓
15.	Paper Planes	✓					✓		✓
16.	Spectroscope	✓					✓	✓	✓
17.	Synthesize the Timbre of Your Preferred Instrument	✓		✓	✓			✓	✓

Table 2.6. Scientific reasoning skills identified by PLCT teachers as skills developed in students during the implementation of the particular IBL units.

In their reports PLCT teachers also included information about the students' scientific literacy acquisitions during their IBL classes. The teachers mostly focused on reviewing prior knowledge (during an introductory, brainstorming part of the lesson or during other discussions). In most of the implementations students could elaborate scientific explanations of the concepts (using scientific expressions). In more than half of implementations development of understanding of the real world context of the topic as well as understanding of the properties of physical/biological/chemical quantities were present. A bit less frequently the implementations promoted evaluation and the design of scientific investigation. In about one third of the examples the understanding of physical quantities was developed. In 25% of the cases critiquing a method and modelling of the physical quantities or phenomena were practiced. In the same number of implementations searching for information in external resources was encouraged. Development of a few other skills was less common and specific to the topic chosen by PLCT teachers for the IBL implementation. Among them - identifying consequences of humans' intervention in the environment, presentation of scientific data in formats like graphs or tables, evaluation of the content (e.d. food, substances) properties, scientific explanation of the phenomena and focus on the rules of a fair test. It might be also the case that these skills were enhanced during more implementations but not reported by teachers. The details are available in Table 2.7.

No.	IBL modul title	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
1.	Alcoholic Fermentation			✓			✓	✓	✓	✓				✓	
2.	Balance of forces and use of trigonometric functions	✓	✓				✓					✓	✓	✓	
3.	Cooler Bag	✓	✓			✓								✓	
4.	Density											✓			✓
5.	Determining Taste Zones of the Tongue	✓	✓	✓					✓	✓					
6.	Earth and Space	✓		✓			✓								
7.	Eco-travelling	✓			✓									✓	
8.	Electrical Circuits	✓	✓	✓					✓				✓	✓	
9.	Electricity	✓					✓						✓		
10.	Exploring the Perimeter and the Area of Complex Objects	✓	✓									✓			
11.	Gravitation, Weight & Centrifugal Force	✓					✓		✓		✓	✓		✓	
12.	Leaking bottle: which water jet is the longest?		✓				✓				✓				
13.	Measurement in Physics			✓											
14.	Moon – Earth's companion	✓					✓					✓	✓	✓	
15.	Paper Planes	✓	✓	✓						✓		✓		✓	
16.	Spectroscope		✓		✓		✓			✓	✓			✓	
17.	Synthesize the Timbre of Your Preferred Instrument		✓	✓		✓	✓				✓				

Table 2.7. Scientific literacy aspects identified by PLCT teachers as developed by students during the implementation of the particular IBL units.

To conclude the set of PLCT teachers' best examples makes up a collection of authentic IBL units, already tried out in the classroom. They are quite diverse with respect to the IBL levels, school subjects, students' age, strategies of the division into groups, and even assessment methods. The collection covers the entire spectrum of inquiry skills, scientific reasoning skills and scientific literacy aspects developed in students during implementation of teachers' IBL units. Together with the description of units, PLCT teachers provided also the linkage to their Practitioner Inquiries based on this IBL modules and their reflections about their own learning during implementations. All these make a collection of rich material for teachers, both those who start with IBL method in their practices and those who have already tried it out.

2.3 THE BEST IBL PRACTICES IMPLEMENTED BY TEACHERS

2.3.1

Alcoholic Fermentation

Carine Vallons, BE

Context and goals

The unit was developed by Carine Vallons, a chemistry and science teacher from Meldert (Belgium).

IBL LEVEL	Almost open, only a little bit of guidance
AGE & SCHOOL TYPE	• 17 yo • general education
GROUPING	• per working in pairs
IBL unit resources	Driving under influence, an IBL Module developed 10 years ago by Hans Bekaert (U. Hasselt, Dutch). The poster made by the teacher.
Key concepts	factors that influence alcoholic fermentation
Inquiry skills developed	• generating ideas in discussion • elaborating research questions • developing hypothesis • planning investigation + present plan • forming coherent arguments • working collaboratively • presentation of the results - to another class
Scientific reasoning	• identification of variables • choosing right components (materials, devices)
Scientific literacy	• evaluate and design scientific investigation • scientific explanation of concepts (use of scientific expressions) • evaluation of the content (e.g.of food, substances) • critiquing a method • searching for information in external sources • understanding the real world context of the topic
Assessment	Formative: discussion and feedback between the pairs, feedback of the peers on each presentation, reflection assessment form of the teacher: the teacher asks in depth questions to each group, triggering new ideas and improvement of their strategies.

Unit description

1. Introduction: **generating ideas in a guided discussion**: alcohol is a killer in traffic. What is alcohol, what does it with your body, where does it come from? Wine growers are interested in the production of alcohol during the fermentation process. It is therefore important to know under what conditions the alcoholic fermentation takes place optimally. This discussion really enhances the **understanding of the real world context of the topic.**
2. **Searching for information in external sources** on this subject for example via several internet sites, then we will dig deeper into that process. Individual tasks:
    a. What is your **research question** and **hypothesis**?
    b. How are you going to **plan the investigation**?
    c. What **materials, components and substances do you need**?
    d. How much time does the investigation take?
3. **Collaborative work**: In pairs: pupils can carry out assignments in which they coach each other, discuss and agree on each of the points a-d.
4. Pupils **prepare collaboratively** (as a pair) a short presentation for their peers of the agreed actions and answers they found to questions a-d.
5. Each pair **presents its presentation to their peers**; in this way the class arrives at coherent conclusions.
6. Other students **evaluate the design of the scientific investigation** of this pair in the class by asking questions and give feedback/their opinion
7. **The presentation is given for another class/year,** ....

Notes.

This section is only one in the bundle. It is a try-out. If students are positive, then the rest of the bundle will be changed accordingly.

Relation between PI and IBL

"What forms of work can students use to draw up and communicate research as independently as possible?" The PI was focussed on understanding to what extent pupils can work independently on (this) topic. The support of the teacher was minimal, only organising basically the learning about a whole cycle of inquiry the students should learn to set up.

Teacher's Learnings

Asking pupils the teacher discovers " Pupils think that: Errors are detected faster; Knowledge of others and continuous consultation lead to creative thinking; Sharing ideas leads to better conclusions; When working in pairs, they are required to actively participate.

These answers of pupils lead the teacher to following conclusions with respect to the future:
About working in pairs - continue to use groups for assignments where multiple answers are possible.
and continue to use groups for assignments that are individually difficult. Also continue to work in groups for extensive assignments.
Keep using the method of making presentations for other student groups.

2.3.2

Balance of forces and use of trigonometric functions

Špela Gec Rožman & Špela Povše Pistotnik, SI

Context and goals

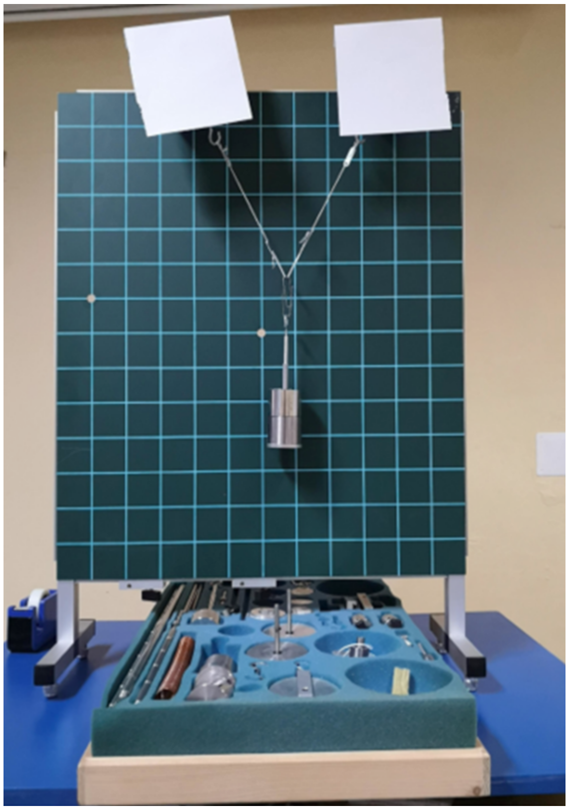
The unit was developed by Špela Gec Rožman a physics teacher and Špela Povše Pistotnik, a math teacher: Academic, Electronic and Maritime High School Piran, Slovenia.

IBL LEVEL	guided
AGE & SCHOOL TYPE	• Students' age 15-16 • School type: technical (electro technical)
GROUPING	• No of pupils per group 4 • Overall No. of classes participating in implementation 1 • single gender (male) • ability-groups: mixed ability • formed by a teacher • classroom space arrangement: nests
IBL unit resources	teacher's own material (weights, strings, force meters, appending board, worksheets for students)
Key concepts	balance of forces, trigonometric functions
Inquiry skills developed	• developing hypothesis, • forming coherent arguments, • working collaboratively, • drawing conclusions, • presentation of the results,
Scientific reasoning	• identification of variables, • making scientific connections, • problem-solving, • making comparisons,
Scientific literacy	• reviewing prior knowledge, • understanding the properties of physical quantities, • scientific explanation of concepts (use of scientific expressions), • understanding of physical quantities, • modelling physical quantities, • understanding the real world context of the topic…

Unit description

Students conduct guided study by following instructions on worksheets and that of the teachers. The students are shown an assembly of strings and weights and are asked to observe the situation and determine the size of the forces in strings. After the calculation of the forces, they compare their value with the measured values. We encourage students to make their own assembly and repeat the action. Students have to detect the angle between the two strings so that the forces in the strings would be equal to the force of gravity on the weight. After writing down their hypothesis, they test it on the appending board with weights and force meters. The transfer of acquired knowledge is tested by an authentic task: how to pull a car out of a ditch using only a rope and a tree on the other side of the road.

Steps of the IBL in more detail



1. The weight is hung on two strings attached to force meters. Students **work collaboratively** at **identifying variables** (forces, angles, mass) and **developing hypotheses** about sizes of the forces in strings. After **solving the problem and presenting the solution**, they **compare** results with measured values. During the task students **use scientific expressions** to explain their reasoning and review their **prior knowledge** of trigonometric functions.
2. Students test their u**nderstanding of properties of physical quantities** by preparing their own composition and **developing hypotheses** of the results.
3. Students present their **hypothesis** about the size of the angle between two strings when the force in strings is as big as the force of Earth on weight. They test their idea with force meters on the appending board.
4. Students test their **understanding in the real world context of the topic** by determining how to pull a car out of a ditch using only a rope and a tree on the other side of the road. They **draw conclusions** and **present their findings**.

Notes.

The students were less independent than expected and the activity took longer than planned, so we improvised by cutting the activity short. Therefore the second task was not conducted.

Relation between PI and IBL

While implementing the unit in our joined class, we carried out our own practitioner inquiry (PI), posing inquiry questions:

1. What are the main obstacles for our students solving problems regarding the balance of forces?
2. To what extent do our students use proper mathematical tools outside math lessons?
3. How many students are able to apply knowledge of Newton's first law and resolve forces to components in an authentic situation?

To find our answers and make our inquiry easier, we prepared spreadsheets to track our observations and marked each group with a number. We wrote several observation points and tried to answer if the students have, have not or have partly

- drawn proper force diagrams
- used proper labelling of the forces
- written proper equations
- marked proper units
- used proper trigonometric functions
- expressed relevant quantities and unknown variables
- understood instructions
- identified the problem (understood the task)
- been able to conduct activities independently
- been active - participating in group work
- been able to use knowledge in authentic situation

We were both supposed to mark observations for each group during activity, but the students needed so much of our attention, that this proved impossible. We later collected their work sheets and took notes of our impressions directly after activity.
We would be much more successful if we decided in advance, that only one of us would be observing students and taking notes, while the other helped students. The discussion and notes we made right after the activity and a second one after we each reviewed students worksheets proved invaluable.

Teachers´ Learnings

Based on our observations, the students were less independent than expected, especially with the first task. They were very unmotivated at first and quickly satisfied with a simplified or even wrong solution of the task, which can be seen in their notes on worksheets. After presenting them with proof of their misunderstanding (measurements on the appending board) they started searching for new solutions.

The analyses of their drawings showed that they did not use the correct labelling of the forces, they did not draw the relevant diagrams of forces, and consequently did not use the diagrams to solve the task.

They needed quite some guidance and motivation to draw the correct diagram of forces. Some problems occurred with identifying the triangle that would enable the use of trigonometric functions. Once the right triangle was recognized, the majority of groups used the correct trigonometric function and consequently expressed the required value.

After this IBL a special activity was conducted in physics class to improve their knowledge of drawing force diagrams and connecting them to real life situations. The graded test that was taken by students a month later showed that their skills and understanding of balance of forces improved.

The students were unable to complete all planned IBL activity as it was too excessive concerning their abilities and motivation. For the same reason our tracking of their results was difficult, almost impossible.

We were surprised to see that heterogeneous groups do not encourage group work. Students who considered their knowledge and skill inferior did not contribute to the common goal and were totally dependent on those considered superior that was observed in all groups involved, except the one that was (by our "mistake") more homogenous than we thought.

Our joined activity was nevertheless successful because students had the opportunity to connect their knowledge of physics and mathematics and also it gave us a new insight on how to improve ourselves as teachers. We are already planning new practitioner inquiries on the subject of the usage of linear, quadratic and other functions in high school physics.

2.3.3

Cooler bag

Barbara Jančič, SI

The unit was developed by Barbara Jančič, a primary school teacher from Osnovna šola Vojnik, Slovenia.

Context and goals

The inquiry was combined. Students first assembled a cooler bag according to instruction within the lesson plans for technology, in the next step they used their cooler bags to study their function during the science lesson.

IBL LEVEL	Guided and open
AGE & SCHOOL TYPE	• Students age: 10 years old • School type: Primary school
GROUPING	• 2-3 pupils per group • 1 class • Groups made: **random** on their gender and capabilities • Groups formed: **by students themselves** • Classroom space arrangement: **individual desks**
IBL unit resources	Some material taken from *Florjančič, F., Zajc, S. Naravoslovje in tehnika 5: navodila za ustvarjanje pri pouku in tehniških dnevih v 5. razredu devetletne osnovne šole. Miklavž na Dravskem polju: Izotech, 2012.* and adapted.
Key concepts	Conductivity, heat conductors.
Inquiry skills developed	• planning investigation, • developing hypothesis, • forming coherent arguments, • working collaboratively, • data gathering skills and analysis skills, • presentation of the results.
Scientific reasoning	• Identification of variables, • problem-solving, • making comparisons
Scientific literacy	• reviewing prior knowledge, • understanding the properties of physical quantities, • presentation of scientific data (graphs, tables), • understanding the real world context of the topic

Unit description

By inquiring my own teaching experiences, I was interested in how Inquiry Based Learning will affect children's independence at work. I was focused on the need for teacher's guidance and on whether an active approach to learning will even be interesting to students at all. For this purpose, I used the activity in which students make a cooler bag on their own and carry out experiments related to thermal conductivity.
The students first made a cooler bag (Florjančič in Zajc, 2012), following instructions and guided implementation (Figure 1). Next, students explored how a cooler bag works. They measured the temperature dependence on time of hot water in a container in the cooler bag and compared it with the temperature of hot water in a similar container outside the cooler bag. Two groups of more motivated students, upgraded the experiment. They wanted to investigate deeper how properties of a cooler bag can influence its function. They assembled new cooler bags or adapted existing ones to test their ideas. In the second research, the students formed inquiry questions and planned the inquiry independently, and they also divided themselves into groups.

Figure 1: Assembling the cooler bag.

Students in these two groups decided to inquire the influence of the thickness of the Styrofoam wall and the size of the cooler bag (Figure 2) on the difference between the temperatures of the water in a container inside and the temperature of the water in a similar container outside of the cooler bag. The aim of the inquiry was that students use as much knowledge as possible gained in the first part of the inquiry in its second second part. They also had to do two new cooler bags on their own.
At first experiment, they put one glass of hot water in the cooler bag and one on the table. Both glasses were the same and had the same amount of water in it with the same water temperature. Then they checked the temperature of water every 5 minutes for the next 25 minutes. They did the same thing at the second experiment, which they did on their own.

(a) (b)

Figure 2: Cooler bags prepared for testing: (a) different thickness of the insulation, (b) different sice of the bag.

I did the implementation plan, prepared worksheets, and instruments for me. Gave them instructions for the first experiment. For the second experiment, I only confirmed their suggestions for the new research. I monitored the students throughout the second research, observed them and guided them minimally when they needed help.

I recorded their work with my notes and analyzed the results based on solved worksheets, which they solved together in a group.
In the research, students came to new conclusions on their own in the second experiment. The knowledge acquired in the first guided experiment was thus used in the new situation. At the end of the experiment, when they confirmed their hypotheses, the students showed a great amount of satisfaction.

At the end of the research, the students came up with new questions, and a desire for new research. During the research, students developed cooperation, critical thinking, group work, consolidated the acquired material and learned something new from the obtained results.

The students came to the following conclusions:
1. The larger the cooler bag, the faster the water temperature drops.
2. The thicker the Styrofoam wall of the cooler bag, the slower the water temperature drops.

Relation between PI and IBL

I was interested in how Inquiry based learning affects children's independence at work. I was focused on the need for teacher's guidance and on whether an active approach to learning will even be interesting to students at all.

The approach to this kind of learning was interesting for the students. Less teacher's guidance was needed for the second experiment, therefore one can conclude that students become quite independent at work rather quickly.

The knowledge acquired in the first guided experiment was thus used in the new situation. During the research, students developed cooperation skills, critical thinking, group work, consolidated the acquired material and learned something new from the obtained results.

Teacher's Learnings

At the end of the inquiry, the students came up with new questions, and a desire for a new inquiry. I was really happy when I saw this. The approach to this kind of learning was interesting for the students and also for me.
I think this is good for my teaching, that we are not afraid of this method and that we use it as often as possible in the class and over time, then our teaching will also get better.

I also got a great insight in other teachers' work in this project and now I have many ideas how I can improve my work.

We also encountered difficulties in learning through inquiry. Some cooler bags assembled by students were not precise, so there were minor deviations in the measurements. It also turned out that students were less interested in recording their work in worksheets and drawing graphs.

Next time I would improve a few points – for example, I would include more students and form more groups to perform the second experiment. I would give students the opportunity to choose their own topic to explore. My practitioner inquiry will be focused more on the role of the teacher during the activity.

References

Florjančič, Zajc (2012). GRADIVO: NARAVOSLOVJE IN TEHNIKA 5, navodila in praktično gradivo za ustvarjanje pri pouku naravoslovja in tehnike ter tehniških dnevih v 5. razredu osnovne šole.

2.3.4

Density

Anna Bekas, PL

Context and goals

The unit was developed by Anna Bekas, a physics teacher from Poland.

IBL LEVEL	GUIDED
AGE & SCHOOL TYPE	• 13yo • primary school
GROUPING	• 4 pupils per group • mixed-gender • random ability groups • formed on random (as they sit)
IBL unit resources	Teacher's own material
Key concepts	density, floating, sinking, mass, volume
Inquiry skills developed	• developing hypothesis • planning investigation • working collaboratively • data gathering skills • drawing conclusions, • presentation of the results
Scientific reasoning	• identification of variables • proportional & inversely proportional reasoning • making connections between scientific quantities and variables • making connections between physical quantities and their units
Scientific literacy	• understanding the physical quantities • fair test
Assessment	• **Formative**: class observation, fast feedback • **Summative**: testing with use of different mathematical representations and testing the development of skills to design own experiment

Unit description

1. At the beginning of the unit learners **brainstorm** about everyday ideas of what is dense and what is not. Among others, teachers ask how to make the soup more dense.
2. The first task is to make an experiment in which you observe what happens to the bodies/liquids of different densities (taken from the tables) when put together. Pupils are given particular substances that do not mix: canola oil, denatured alcohol (dyed), ice cubes. Students **put forward hypotheses** and carefully **conduct** the experiment and take notes.

3. Students **compare** the result of their experiments with densities of given substances gathered in tables and **draw conclusions** on the basis of this comparison.
4. Then **discussion** in the classroom **about the results** obtained by different groups takes place.
5. The second task is to perform an experiment, finding out what is the relation between density of different solutions of table salt in water and mass of these solutions. Density is not determined quantitatively by calculation with use of density definition (which they do not know yet), but it is determined quantitatively with use of an egg and initial observation that the egg sinks in pure water (of density 1 g/cm3).
6. Then pupils **perform the experiment**, controlling and changing the amount of salt mixed with water, making sure that every time the volume of the solution should be kept constant. (If possible, scales could be used to weight solutions, but it was not the case). **Brainstorming** about the necessity of keeping fixed the volume of the solution precedes the experiment. Teacher introduces the idea of a **fair test**.
7. **Pupils take notes** during the experiment. They compose the **plan of the experiment** in groups, **perform the experiment** and **draw conclusions**.
8. **Groups present** results on the forum and draw the conclusion that density is somehow proportional to mass.
9. The third task is to prepare two solutions of table salt in water (with distinguishable difference of salt mass), keeping the mass of solution constant. Students **perform** analogous **experiments**, using an egg and on the basis of observations they **draw conclusions** about the relationship between the density of table salt solution in water and its volume.

Notes.

Experiments ended up in more quantitative than qualitative results, so derivation of exact proportional or inversely proportional relation was not possible. This happened because the students were in their first year of studying physics and more than a half of them hold certificates of different kinds of disorders. In such circumstances, conclusions that density monotonically increases with mass and monotonically decreases with volume are sufficient to justify subsequent introduction of an exact definition of density.

Relation between PI and IBL

While implementing the unit in her two classes, the teacher did her practitioner inquiry (PI), posing a research question:

> *How does the IBSE method affect the memorizing of physical quantities and the application of acquired knowledge in practical algebra tasks?*

In her PI the teacher focused in particular on the influence of planning and doing experiments on memorizing physical quantity and its units. Some attention was paid to her performance of students with special needs.

Teacher's Learnings

Quite surprising to me was that performance of relevant experiments positively influences memorizing of physical quantities and their units. Quite a lot of students (80%) recall performing experiments when asked about density and admit that this recollection helps them solve algebra tasks. Since most students (83%) perceive IBL lessons as motivating and more interesting than traditional classes (survey results) I believe I have more motivation to use IBL method, even in topics where experiments are not demanded by curriculum.

It is important to me that even some pupils with disorders did quite well with memorizing physical quantity (density), when they attended IBL classes.

2.3.5

Determining taste zones of the tongue

Guy Puttevils, BE

Context and goals

The unit was developed by Guy Puttevils, a biology teacher from Meldert (Belgium)

IBL LEVEL	Guided
AGE & SCHOOL TYPE	14 yo, general education
GROUPING	groups of 3
IBL unit resources	Poster of ME
Key concepts	taste of substances, zones of the tongue
Inquiry skills developed	• generating ideas in discussion (within small groups) • elaborating research questions (in small groups) • planning investigation + presentation of the plans • discuss about a whole class investigation plan • working collaboratively • data gathering skills • drawing conclusions
Scientific reasoning	• identification of variables • choosing right components (materials, devices) • problem solving • making comparisons
Scientific literacy	• reviewing prior knowledge • understanding the properties of biological/chemical substances • evaluate and design scientific investigation • critiquing a method • searching for information in external sources

Unit description

1. **The teacher leads the discussion to generate ideas**: we taste different tastes with different zones on our tongue, we want to know more about this. For class A the guiding questions to enhance their **thinking about their prior knowledge** are : What flavors are you going to explore? What substances will you use to investigate each taste? How are you going to prepare those substances? How/what are you going to apply these substances to the tongue? Where on the tongue will you test? Must the mouth be rinsed between each taste sensation, how? What order of work are we going to follow? How are you going to write down the results? Who takes care of the materials and substances? In another class, class B: the questions above were NOT asked, the pupils needed to **search for information in external sources** first individually, exchange the information within small groups and after that **work collaboratively** to end up with a series of possible questions as above.
2. Each **group poses a research question** which is based on the above ideas or is a totally own research question.
3. The whole class then decides on one question, see worksheet.
4. Each group **plans a research plan** to find the answer to their research question: they **identify a variable, choose right components (materials, substances), make a risk analysis for safety**, develop a method of action and measuring and data gathering, anticipate and solve practical problems.
5. One representative of each group **presents their research plan** to the rest of the class
6. The other pupils evaluate each others' scientific investigation and write down what they think is good or not necessary about the research plans of the other groups, **critiquing this way each others' method**.
7. Through a class discussion, each group updated the **design of the investigation plan**.
8. The student groups carry out their partial research: they gather data- write them down in their own way and draw conclusions
9. They reflect on the working method with 3 open questions (see worksheets).

Assessment methods incorporated into IBL

Formative: oral peer assessment (immediate feedback) on presentations of peer groups' inquiry plan, open reflection by the pupils:

- Is your hypothesis correct? If not, improve and formulate a more correct hypothesis.
- Reflection on the research. (Did the investigation proceed as expected or were there corrections necessary?)
- Reflection on research attitude. (How was the cooperation within the group? Remarks)

and observations and feedback of the teacher

Summative: the group report of the lab was assessed (7points), as usual, focussing more on the outcomes of the research (content), and the attitudes were assessed (3 points).

Relation between PI and IBL

The PI question was: " How can I involve students more in the design of a research plan in a scientific study?", in this case more specific: "How can I involve students more in the design of a research plan for determining the taste zones on a human tongue?"
Two classes: Class B: rather high level class, and a class A that needed a lot more guidance, but this was planned.

The outcome of this PI is given in the observations of the teacher:
Class A: Big differences between groups of pupils: some do not get further than a number of incoherent ideas, other groups work a bit more structured. The presentation of their research plan to other groups goes quite smoothly. The other groups listen but note little or nothing. Drawing up a joint research plan through a class discussion goes smoothly, but the teacher still has to steer strongly.
Class B: These research plans of the groups are more structured and more complete. Consideration is also being given to recording the results and practical arrangements for the implementation of the research. When the research plans are presented to each other, the other groups take note of a few comments. Composing a joint research plan via classroom discussion goes smoothly, but even now the teacher. still has to steer. However, a dynamic and constructive conversation does arise.

Student's reflections: POSITIVE: "We learned more to think logically in a practical class." "Fun to do and nice atmosphere" "You can choose the way you do it" "You learn to consult a lot" "In smaller groups everyone can work on their own things and can compare results later on". Nice to work independently and to be allowed to work out your own ideas" "Teaching to put things to the test" "More fun than normal practice" "More fun, it comes from yourself" "Being able to think about how we are going to investigate things" "Being able to think about how we are going to investigate things for ourselves"
NEGATIVE: "There's not much help with research and that makes me nervous", "We weren't told when we're doing something wrong, I think it's important", "It takes too long sometimes", "You don't immediately know what and how to do it", "It's more fun and convenient if we have to follow a step-by-step plan". You notice that it was the first time, next time mss a little more guidance", "It's a mess when we make a common plan with the whole class", "Sometimes difficult to find a next step" "difficult to come up with your own tests, prefer the old practice", "A bit slow, mss more independence next time", "Sometimes you're wrong for a quarter of an hour or more and that's how you waste your time".

Teacher's Learnings

Encouraging students to develop their own research plan (research method) independently in groups is certainly motivating and enriching for pupils due to the fact that they are not yet very familiar with practical and investigative thinking, some pupils feel insecure when this method is used and like to go back to a structured plan that they just have to follow. However, most are more motivated to draw up and elaborate their own research in a group. Gives them more satisfaction that they have been allowed to prepare their own research. The fact that they are still 3rd year students, they still like the fact that they get some tips to work out their research. Drawing up a joint research plan together with sometimes their own specific input (their own ideas) is still necessary in order to avoid chaotic and incoherent research afterwards. It is useful and instructive for pupils and teachers to actively involve pupils in the development of a research plan (-method) in practicals as early as the 3rd year. Due to lack of experience from the first degree, they still need to be guided in this process. It also takes a lot of time to work in this way (4 lessons for one lab). Not every lab can be done this way. I think this can only happen two or at most three times in a school year in a Sciences class with 2h/week. In 1h/week classes this seems almost impossible.

Supporting material

Additional material available:
- Student worksheet in English
- Example of student worksheet (Dutch)

2.3.6

Earth and Space / Variables and Experimental Design

Caroline Quirke, IE

Context and goals

The unit was developed by Caroline Quirke, a Biology and Junior Certificate Science teacher from Ireland.

IBL LEVEL	Guided
AGE & SCHOOL TYPE	• 14 yo • lower secondary
GROUPING	• Three students per group • One • Single gender – male school • Mixed ability • Formed by a teacher • Laboratory classroom with desks in rows and Demonstration room with tiered seating
IBL unit resources	These were a combination of teacher's own resources and adapted material
Key concepts	The concepts were taught from the Irish Curriculum Strands – Nature of Science and Earth and Space. The key concepts covered were, experimental design and terminology, fair and accurate testing, celestial bodies in space, gravity, collisions, rates of reactions, mass and rockets/space travel.
Inquiry skills developed	• Developing hypothesis • Planning investigations • Forming coherent arguments • Data gathering skills • Data analysis skills • Drawing conclusions
Scientific reasoning	• Identification of variables • Making scientific connections
Scientific literacy	• Reviewing prior knowledge • Evaluate and design scientific investigations • Scientific explanation of concepts (use of scientific expressions)
Assessment	**Formative**: classroom dialogue, teacher observation, worksheets **Summative**: teacher observation and worksheet

Unit description

This inquiry unit was taught to 14 yo students in an Irish lower secondary setting. The context of the lessons was the Nature of Science Strand on the Irish specification. This strand was introduced through tasks and experiments in the Earth and Space strand. The core focus of the unit was to develop students' understanding of variables and experimental design.

The initial activity involved a guided inquiry worksheet relating to an asteroid hitting the surface of the Earth. The guided inquiry worksheet challenged students thinking about **experimental design and variables** by requiring them to design a series of experiments **and analyse data**. There were three tasks for students to complete. Before each task, there was a series of probing questions for the students to answer and after, there were reflective questions based on the task.

The first task on the worksheet asked students to drop a marble (asteroid) into a container of flour (Earth's surface). Then they had to think about what effect changing the mass of the asteroid may have on the Earth's surface (flour). Following this, students were allowed to make any changes to the experiment. After planning their experiment, some groups opted to change the height, others changed the material the surface of the "Earth" was made of and another group decided to look at what effect an irregular shaped object would have compared to a smooth-edged marble. Students were not specifically introduced to the terminology of independent or dependent variables at this stage, yet through the task they were able to identify the variables and the majority of the class chose to change only one variable when designing their own experimental procedure.

In the second task, based on their completion and reflection of the first worksheet, students brainstormed individually, then in their small groups before sharing with the class they discussed what they taught was important to consider when planning an experiment. During this task, as a class group they highlighted all the key points, however it was observed that they lacked the appropriate terminology. For example, one student highlighted the importance of making a "theory" before conducting the experiment. When questioned further it was evident that he was talking about a prediction prior to the experiment. Hence, the teacher then introduced and explained the terminology including, variables, hypothesis, research question, design etc. These were explained in the context of the initial task. Students then completed an assessment worksheet to evaluate their understanding of the terminology and their ability to identify variables.

The final task was an open question given to the students. They were asked to design an experiment to investigate if the amount of fuel used affects the time it tasks for a rocket to launch. They were required (in groups) to design an experiment with clearly identified independent and dependent variables. They were told the materials they were going to be provided with. For health and safety reasons a teacher demonstration of how the equipment should be used and the safety procedures that had to be implemented was explained. On the day of the experiment, students, in their groups, wrote out their experimental procedure which the teacher signed off as long as there were no health and safety issues. All of the groups designed experiments which demonstrated clear understanding of experimental design and variables.

Relation between PI and IBL

The focus of the practitioner inquiry was to investigate ways of introducing students to the concepts and understanding of variables and experimental design. The PI question was:

How can I support students in their learning of experimental design strategies through inquiry-based learning?

The teacher explored if reflection on a guided inquiry worksheet is a good approach to introduce this terminology instead of starting with the terminology and then getting students to complete the task. It was found that the approach worked in that the majority of students were able to identify variables and distinguish between dependent and independent variables when considering the example of an asteroid striking Earth. This learning was then used to teach students how to design fair tests and use good experimental design. It was found that students understood the concept of variables by introducing them through a context and the teacher would advocate this approach in future. It was specifically observed that the approach adopted was very effective lower ability students and those with identified learning difficulties. They found the terminology more tangible and less daunting than if introduced in a classroom using the traditional method. This method led to more meaningful understanding for these students and as a result improved their long-term retention of the information.

Teacher's Learnings

Through this PI activity the teacher learned an effective way to introduce students to new terminology. It was found that reflecting on activities was better than teaching the terminology first. It was noticed that some students found it difficult to identify variables from a written text. It's not certain if this has to do with their literacy levels. This will be a future PI worth exploring. It was also learned that introducing students to the experimental design process through the lens of variables improved their understanding of hypothesis, fair testing and design skills.
In terms of the PI process the teacher learned the importance of trialing data collection tools. In this task, the wording of some of the questions on the assessment were a little vague, hence it was difficult to make definite claims on some aspects of the PI. In future the teacher will ensure that the data collection tools fully align to the inquiry question.

2.3.7

Eco-traveling

Rita Deraedt, BE

Context and goals

The unit was developed by Rita Deraedt, a chemistry teacher from Land-en tuinbouwschool Oedelem (Belgium).

IBL LEVEL	Guided
AGE & SCHOOL TYPE	• 16 yo • secondary school for agriculture and farming
GROUPING	• four students per group
IBL unit resources	Module Eco-traveling developed by STERCOLLECTIE (Netherlands) available at https://maken.wikiwijs.nl/61161/Thema__Ecoreizen___De_reis__Scheikunde_VWO_4.
Key concepts	Concepts for chemical calculations: Atomic mass unit, (unit of measurement for) amount of substance (mole), molar mass, molar concentration, Concepts related to sustainability and sustainable
Inquiry skills developed	• generating ideas in discussion • developing hypothesis • planning investigation • forming coherent arguments • working collaboratively • drawing conclusions • presentation of the results
Scientific reasoning	• problem solving • making comparison
Scientific literacy	• reviewing prior knowledge • identifying consequences of humans' intervention in the environment • understanding the real world context of the topic
Assessment	**Formative**: worksheets form several activities, teacher observations, classroom dialogue **Summative**: presentations of students, test on chemical calculations

Unit description

The focus of this series of more than 10 lessons is to make the rather abstract theory on chemical calculations more meaningful in a specific context by posing a challenge.

1. Engage & excite: During the introduction a travel agency 'Ecotraveling inc' set up a kind of a contest to design the most green and sustainable trip around the world. This contest challenges them **to solve this problem**.
2. Engage & Excite: After the introduction, students are challenged through an assignment to list what they now need to know, to investigate in order to achieve a green and sustainable journey. In these discussions the emissions of CO2 play an important role, so the key questions will be 'How much CO2 emission do you produce during your journey?' They have **to understand the real-world context of the topic, generating preliminary ideas** about the trip and transport and **raise questions**, not specifically research questions (they can be) but most of all about things they need to know and investigate.
3. Explore: **Reviewing prior knowledge** and **gaining new knowledge**. Depending on the needs of your class several activities can be done in order to support them in finding an answer to the challenge: greenhouse effect, extra support to practice math, extra experiments on chemical reactions, theory on sustainability… Students rearrange that new knowledge and to fit into the knowledge they have previously constructed. Also the rules and conditions for the challenge are being described more specific:
    - You have 10 days to travel around Europe. You leave your hometown and have to get out there after 10 days.
    - You will visit at least 4 of the following cities: Krakow, Dublin, Ljubljana and Istanbul. You indicate how long you stay there for each city.
    - You can keep CET time anywhere.
    - You must use at least four different modes of transport, one of which is the bioethanol car.
4. Explain: In the next step students will answer the **key question & solve the problem** by calculating the CO2 emissions of their proposed journey.
5. Evaluate: They **present their results** to the other groups in class.
6. (Optional) Extend: New knowledge about chemical calculations is being **practiced in other & new contexts.** Also questions that have not been answered from the engage-stage can be listed and if possible answered in a new series of lessons.

Relation between PI and IBL

The teacher chose the following inquiry question:

> *In what way can I increase the motivation for the lessons on chemical arithmetic among less mathematical students and thus achieve deeper learning?*

She used the Eindhoven study on 'arithmetic of reactions, an intervention in which deep learning is central' and the materials from "project ECOReizen TUDelft" to prepare an intervention. She didn't exactly copy it but adapted it to her needs and context. There was extra attention to mathematics (in consultation with the mathematics teacher) about converting units and formulas, ... and using the context of environmental travel. This led to the key question: "how many kg of CO2 is emitted by a car and airplane when travelling from Zaventem to Marseille?" This was structured very similar to the unit described above in the following steps: discussion, plan of action, calculate & exchanging results.
During the intervention the teacher collected data in diverse ways: notes from students, teacher's notes, student survey and a test on chemical arithmetic.

Teacher's Learnings

Motivation for stoichiometry by working with context is greater (students want an answer to the question of CO2 emissions).
The students had less the feeling that they were learning chemistry and using mathematics because they had more ownership through the assignment. However, the assignment (presented as a challenge) cannot be too open. Otherwise, you cannot respond enough to questions of your students. Without clear guidance (via a worksheet) it is rather difficult for students to come to a successful conclusion.
Because of the COVID-19 crisis it was difficult to make clear conclusions from the final exam (which included the topic of stoichiometry), but a short in-between test was very promising.

Advice to colleagues:

- Pay sufficient attention to prior knowledge,
- Use both mathematics and chemistry skills and support the learnings of your students for these two subjects.
- Choose context of real world close to the interest of the students
- Provide sufficient course hours! It takes time but it certainly has an added value.
- Make sure the assignment is defined enough. Don’t provide open challenges and instructions.

2.3.8

Electrical Circuits

Renata Szyndak, PL

Context and goals

The unit was developed by Renata Szyndak, a physics teacher from Poland.

IBL LEVEL	STRUCTURED/GUIDED
AGE & SCHOOL TYPE	• 18-19yo • High school and technical school • 3 classes, 96 students
GROUPING	• 3-4 pupils per group • mixed-gender (however boys were in majority) • random ability groups • part 1 - formed by students; part 2 – selection by a teacher
IBL unit resources	Teacher's own material
Key concepts	Electrical circuit, voltmeter and ammeter, electrical components
Inquiry skills developed	• developing hypothesis • planning investigation • forming coherent arguments • working collaboratively; effective time management • data analysis • drawing conclusions
Scientific reasoning	• "reading" electrical circuits schema with comprehension • comparison between theory and practice • understanding practical limits of the model
Scientific literacy	• understanding the properties of physical quantities, • evaluation and design of measurement sets • identification of the consequences of incorrect connection of electrical components • constructive criticism of the method • modeling of current flow processes • understanding the context of the topic in everyday life - the difference between the model and the real measurement system • review of prior knowledge • understanding of physical quantities
Assessment	**Formative**: group oral report, presentation

Unit description

Due to the lack of equipment in the school laboratory, the teacher chose the method of modelling electric circuits instead of building the real ones. Having only two ammeters, one voltmeter and four resistors per class, the teacher could not conduct a lesson on connecting the real electrical circuits.

PART 1 (groups formed by students):

1. Division into groups; students formed the groups by themselves. One half of students worked in groups of four, the other half – in groups of three.
2. **Brainstorming** about the current knowledge of electrical current and electrical meters.
3. Getting familiar with real ammeters, voltmeters, cables and batteries
4. Acquainting with the real devices: meters, cables, receivers and possibilities of connecting these components.
5. Presentation of the problem – a diagram of an electric circuit drawn on the board by a teacher.
6. Selection of elements for which parameters will be measured.
7. Distribution of materials for modelling work (cards, threads, plasticine, markers, scissors)
8. Students' **collaborative work – planning**: division of tasks, resource management, establishing methods of conducting the experiment, discussions.
9. Design of a model electrical circuit. Presentation of the models to others.
10. **Group reflections** on the task performed.

PART 2 (groups formed by a teacher):

11. New groups selected by a teacher. Those who worked in part one in groups of four were divided into groups of three and vice versa.
12. Presenting on the board a diagram of a different electric circuit and repeating steps 6, 7, 8, 9 from part 1.
13. **Reflection** on the course of work in a group, **critical evaluation** of mistakes made during work, **conclusions** from the work, **suggestions formed** for the future work in order to optimize work efficiency (among others: **time management**) - **presentation** by individual groups.

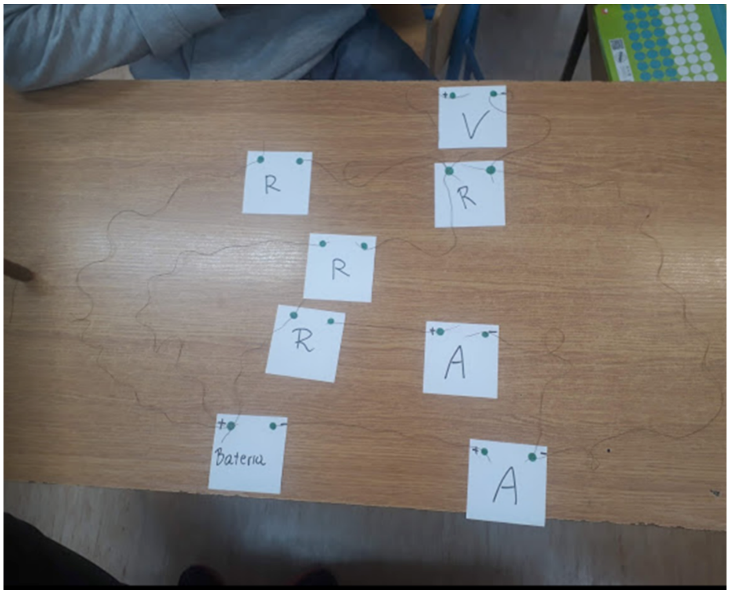


Fig. 1 Modelling an electrical circuit with use of: cards, plasticine, pieces of thread.

Notes.

The teacher took advantage of having a very poorly equipped school laboratory and proposed an IBL lesson in which students modelled real electric circuits.

Relation between PI and IBL

While implementing the unit in her three classes, the teacher did her practitioner inquiry (PI), posing a research question:

> *Does a student work better in a group of three or four and what are the determinants (advantages, disadvantages and limits) of this choice?*

The PI research question was directly related to the work with the IBL method. The surveyed students had previous experience in working with this method. The form of the classes was chosen to emphasize the researched determinants, supporting students' own reflections on advantages, disadvantages and limits of the choice of groups of three or four students. Conclusions presented by the respondents enabled the teacher to optimize the method of selecting groups for specific tasks carried out using the IBL method.

Teache's Learnings

During the implementation of the-above-mentioned unit and other IBL units I have learned how to manage the work in groups where students work independently from myself. In particular: how to divide students into groups, predicting students behavior when working in groups, preventing deconstructive behavior, planning subsequent steps of the lesson, matching tasks to students' manual abilities, predicting the time necessary for students to complete the task, creating problem situations, selecting previously given instructions - necessary to emphasize the elements of students' work required by the teacher, monitoring group work, asking engaging questions, creating an atmosphere that inspires cooperation in groups, monitoring students during their independent work.

I was totally surprised how consciously and openly students answered my open-ended survey, reflecting on advantages, disadvantages and limits of working in groups of four or three. I have collected elaborated answers from 75% of my students, although the survey was not obligatory.

2.3.9

Electrical Flow

Seán Kelleher, IE

Context and goals

The unit was developed by Seán Kelleher, a lower secondary science and senior cycle chemistry teacher, and lower secondary science State Examiner, from Ireland.

IBL LEVEL	Guided
AGE & SCHOOL TYPE	• 15yo • Lower secondary
GROUPING	• 4 pupils per group and pairs • Two x 40-minute lessons • Single gender (male) school • Mixed ability • In these tasks' students are able to self-select their groups • Laboratory environment, benches are in rows
IBL unit resources	Teacher's own material, informed by previous involvement in Establish/Sails and largely by peer discussion/critique during 3DIPhE
Key concepts	Electricity, Electric Circuit, Insulators, Conductors
Inquiry skills developed	• Generating ideas in discussion • Developing hypothesis
Scientific reasoning	• Making scientific connections • Problem solving (circuit assembly) • Making scientific connections by the facilitation of student discussion
Scientific literacy	• Reviewing prior knowledge • Scientific explanation of concepts (use of scientific expressions) • Modelling physical quantities
Assessment	**Formative**: worksheets, teacher observation, classroom dialogue, teacher questions **Summative**: worksheet

Unit description

The focus of this lesson was to develop students' understanding of electrical flow through simple inquiry activities and prompt questions. The students' previous introduction to the concept of "charge" was encountered when learning about atomic structure. The unit was taught across two linked lessons. In these, students completed a pre and post activity worksheet, an inquiry activity using an energy stick and experiments on electric circuits which was supported by a worksheet. The details of these tasks are now explained together.

Students were first asked to complete a pre-activity worksheet. This was a mix and match activity. Students had to match the terms 'circuit', 'insulator', 'conductor', and 'electricity' to relevant descriptors such as 'does not allow electricity to flow through it easily'. There were more descriptors than terms and students were only allowed to use each term once. Students did experiments to investigate flow of electricity. In the first lesson, they were provided with an 'energy stick' which lights up when held in a closed circuit. In the second lesson students were given a range of conductors and insulators which they used to conduct simple inquiry activities to determine the properties of the equipment provided. This was supported by a worksheet. Some of the substances that students had to test included, tap water, saltwater, cooking oil, a wooden ruler and a lemon.

During the tasks in lesson 1 and lesson 2 the teacher used multiple prompt questions to generate dialogue, challenge students' thinking and give them opportunities to develop and test hypotheses. The approach the teacher used related to the task at hand, some of these were to the whole class, some to groupings and some to individuals. The approach depended on the stage of the task and how students were organised in the class. In all occasions the approach was to prompt students and encourage them to think about the concepts being taught. Students responded as individuals or as a group when working with peers; this was dependent on the stage of the activity and whether they were working in small groups or as a whole class. Examples of prompt questions used include: *What is this device? Why is it lighting/making noise? Why is it still working in a "daisy chain? If one person breaks contact, why does it stop working? Does the daisy chain length have an effect? Is there anything moving through the daisy chain? Is the daisy chain a circuit? Can humans conduct electricity? How? Are there faulty components? What do you think conductors and insulators are?*

Following the inquiry activities, students completed a post questionnaire. This had a similar format to the pre-questionnaire in that they had to mix and match terms to descriptors. However, an extension of the worksheet required that students now provide justification and reasoning for their answers.

Relation between PI and IBL

The teacher chose to investigate the use of prompt questions when teaching electricity. The specific inquiry question was:

> *How can prompt questions develop students' understanding of electrical flow when conducting simple inquiry activities?*

In the practitioner Inquiry the teacher gathered evidence on students' understanding using a mix of data collection approaches/tools including, pre and post-tests, in class worksheet and teacher observations. For the latter, the teacher observed student actions, took note of their responses to teacher prompts and observed their interaction with peers.

Teacher's Learnings

The teaching felt that their practitioner inquiry and lesson went well. The teacher learned for each session as outlined below:

Lesson #1

- The prompt questions made a significant difference in generating open discussion in the lesson.
- In Lesson 1 (40 mins) the teacher used a relaxed to-and-fro discussion approach. This allowed the students to gain a better understanding of 'circuit' & 'electricity' concepts. Almost the entire lesson was given over to these two concepts, which is very different to the traditional approach of providing a definition and proceeding to confirm the definition by experiment/demonstration. Common understandings of the concepts arose from extended discussion which were driven by prompt questions. A reduced pressure on time allowed the concepts to "breathe", possibly from the reduced concept load for students, and slower pace of lesson.

Lesson #2

- In Lesson 2 (40 mins), a very simple circuit was used. This allowed integration of trouble-shooting skills i.e. component-by-component circuit expansion, and reverse process deconstruction when tracing faults with the circuit. This approach also helped students to understand that 'complete' in an electrical circuit, means an unbroken circuit/chain, without any gaps, and with good surface contact from one component to the next.
- The teacher learned that it would be better to reframe worksheet questions as "Are all insulators the same? / Are all conductors the same?". This was based on the realisation that students were being funnelled into a simplistic dichotomy of classification instead of degrees of classification.
- The time pressure in this lesson restricted the IBL nature of the lesson. On reflection, the teacher felt it required a further 40min lesson to tease out concepts for students more comprehensively and to lay a better foundation for further learning in electricity.

Overall Teacher reflections

- The teacher noted that guided/prompt questions and discussion time seemed to improve student understanding. However, it was felt that more time was needed to tease out student justifications, in order to check conflicts between prior and new knowledge and misconceptions. The teacher planned to use follow up lessons on the topic of electricity to further evaluate if the two lessons helped them to develop a clear scientific understanding of these concepts. The teacher also plans to use opportunities to clarify a common scientific vocabulary. This is to support student learning, but it is also planned as the teacher wants to be sure that he is not misconceiving student understanding due to their imprecise or unsophisticated use of language. This is a specific interest of the teacher as he also works as a State Examiner in lower secondary science. He is interested how imprecise or inconsistent use of language by teachers and students can affect understanding and exam performance. This is planned for a future PI that emerged from this work.
- There was no significant difference between students who studied Technology and those that did not. The teacher expected that students experiencing the use of electrical components in another course would have a deeper or alternative, and equally valid understanding of electricity. Students seemed to have a utilitarian understanding of some components, in the sense that they knew what components to string in a circuit and in what order, to make it work, but not necessarily why.

- It was observed that the discussion on non-conduction of some conductive materials allowed a further exploration with respect to voltage and resistance. Not every conductive material tested conducted electricity immediately. This was largely due to poor contact, especially when in the daisy chain. There were also several moments where it appeared that a charge had to "build up" in the circuit, before the energy stick activated. Two students extended this idea. If there was proper and sufficient contact between all components in a circuit, and all the components were electrically conductive, but the energy stick/bulb did not light, what could cause this? Students seemed to suggest that an intrinsic impediment to electrical flow i.e. resistance. The question of how to overcome this was also asked, suggesting an opportunity to discuss voltage and current in relation to resistance. This reflection shows that the use of prompts and discussion in inquiry setting opens up opportunities for learning and thinking that would not normally occur.
- A proposed extension of the inquiry activities is to ask students "Is it possible that a circuit is complete, but electricity cannot flow through it?". This planned follow-on activity is intended as an introduction of resistance and the overcoming of it by increasing voltage or current and unifying this through an exploration of Ohm's Law. This was asked but there wasn't enough time to explore it. This would be beneficial in a third or fourth lesson using the same guided/prompt question and discussion approach where students' complete inquiry tasks to deepen their understanding of the concepts.

Supporting material

Additional material available:

- Student worksheet
- Pre-test
- Post-test

2.3.10

Exploring the perimeter and area of complex objects

Simona Verdinek Špenger, SI

Context and goals

The unit was developed by Simona Verdinek Špenger, a math teacher at primary Brezno-Podvelka school from Slovenia.

IBL LEVEL	guided
AGE & SCHOOL TYPE	• students' age: 11 years • school type: primary school
GROUPING	• no of pupils per group: 4 • overall no. of classes participating in implementation: 2 • gender: random • ability-groups: mixed ability • formed: random • classroom space arrangement: nests
IBL unit resources	teacher's own material
Key concepts	perimeter and area of complex objects
Inquiry skills developed	• developing hypothesis • drawing conclusions • measuring methods • record of conclusions
Scientific reasoning	• reasoning • problem-solving • making comparisons • application of acquired knowledge in a new situation
Scientific literacy	• reviewing prior knowledge • understanding the concept of perimeter and area of the composed objects • understanding the properties of perimeter and area of complex objects • understanding the content after experimenting
Assessment	**Formative**: The students did not get a grade for this inquiry, but it was checked with use of a calculation task how effectively the students learned the material and if they know how to use the acquired knowledge in a new situation.

Unit description

Students were divided into four groups of four students by lot. The inquiry was conducted in a guided manner, with the help of a worksheet.
Pupils investigated two different composed objects consisting of three school desks. One object consisted of square desks (Fig. 1a) and the other of rectangular desks (Fig. 1b). Their task was to find what happens to the area and the perimeter of a composite object if one changes positions of desks and the desks have to be in contact along the entire side. The first two groups investigated first the object composed of rectangular tables (Fig. 1b), and the other two groups investigated the object composed of square tables (Fig. 1a). After 20 minutes, the groups swapped, so each group explored both the rectangular and the square tables.

Figure 1: Composed object from (a) square tables and (b) rectangular tables

Pupils first wrote from which tables a specific object was made of and calculated its perimeter and area. Next, they wrote their hypothesis on the perimeter and the area and performed experiments. They used a carpenter's meter, a calculator and a worksheet on which they recorded their findings. They sketched different arrangements of tables, measured and recorded dimensions needed for calculation of perimeters and areas, and calculated them. Based on the obtained results, they confirmed or refuted the hypothesis.
All groups came to correct conclusions. Pupils found out that moving symmetrical tables does not change the area of the composite object (all groups made the correct hypothesis). Even though they knew that for a perimeter they have to add up the lengths of all sides, some have made the wrong hypotheses. Interestingly, those groups that first investigated compositions of rectangular tables hypothesized that for square tables the perimeter is not always the same (as found for rectangular tables) in contrast to, those groups that first investigated the movement of square tables in the case of rectangular tables. They hypothesized that, in addition to the area, the perimeter is always the same (as found in the case of square tables).
After 6 months, I gave the following task to the students:
Three symmetrical squares are given (Fig. 2). From them, assemble the figure so that the squares will touch along the entire length of the side and the resulting figure will have the largest perimeter.

Figure 2: The test task.

The task was solved individually. Students who participated in this inquiry found the correct answer faster (the perimeter is always the same) than students who did not participate in the inquiry.

Relation between PI and IBL

I carried out the learning activity with inquiry in one group of students, and the other group was taught the same learning material without an inquiry activity. After discussing the subject matter, both groups solved the same tasks. After 6 months, I checked how effectively the students had mastered the learning material and if they knew how to apply the acquired knowledge in a new situation. I was also interested how much time the students needed to draw conclusions. I also checked what misconceptions remained after experiments. I monitored students' work and consideration, recorded the time they needed to form a conclusion, checked the worksheets, and compared the results of both groups.

Teacher's Learnings

Students were enthusiastic about the way of work, they were motivated to work, the work in the group was relaxed. Interestingly, the initiative for practical work was taken by students with poorer academic performance.
When measuring the lengths and widths of individual tables, there were small deviations (differences of about 2 mm). I also expected this, so they were instructed to use the same, rounded value for dimensions of all three tables.
During the implementation of the presented learning unit, it turned out that after 6 months students from the group doing inquiry mostly came to a conclusion faster than in the first inquiry. They also came to the conclusion 75% faster than students who did not participate in the inquiry. The differences were most visible with students with poorer academic performance. There were almost no misconceptions among the students from the group doing inquiry after the experiments, only one student wrote the wrong conclusion, while the students from the other group had several wrong conclusions.
Pupils need "own experience" for longer knowledge and better understanding and faster retrieval of knowledge, they must be actively involved in the process of acquiring knowledge and research. Therefore, I will continue to try to include this way of working in my lessons as often as possible.

2.3.11

Weight, centrifugal force and motion in gravitational field

Beata Świder, PL

Context and goals

The unit was developed by Beata Świder, a physics teacher from Poland.

IBL LEVEL	STRUCTURED
AGE & SCHOOL TYPE	• 16yo • High school and technical school • two classes, 62 students
GROUPING	• 5 pupils per group • mixed-gender or not depending on students' choice • random ability groups • groups formed by students
IBL unit resources	Teacher's own material
Key concepts	(1) centrifugal force, (2) free motion in gravitational field and (3) weight and weightlessness
Inquiry skills developed	• formulating hypothesis • forming coherent arguments • planning investigation • working collaboratively • drawing conclusions
Scientific reasoning	• identification of variables • choosing right components • making scientific connections • solving problems • making comparisons
Scientific literacy	• reviewing prior knowledge • scientific explanation of concepts (use of scientific expressions) • critiquing a method • scientific explanation of phenomena • understanding of physical quantities • understanding the real world context of the topic
Assessment	**Formative**: group work observation **Summative**: test at the end of the series of lessons

Unit description

Two classes took part in three lessons on (1) centrifugal force, (2) free motion in gravitational field and (3) weight and weightlessness. Class A (humanistic, 30 students, mostly girls) followed topics 1 & 3 with use of the IBL lesson format and topic 2 – in traditional format; class B (bio-chemical, 32 students, mixed-gender group) followed topics 2 & 3 with use of the IBL lesson format and topic 1 – in traditional format.

1. Division into groups; students formed the groups by themselves.
2. **Brainstorming** about the current knowledge of weight, weightlessness and centrifugal forces on the basis of students' knowledge from different sources and everyday context.
3. Inquiry questions posed by the teacher.
4. Distribution of materials
5. Students' **collaborative work – planning**: division of tasks, resource management, establishing methods of conducting the experiment, discussions.
6. **Group reflections** on the tasks performed.
7. **Summary** by the teacher

Fig. 1 Collaborative work: discussions, performance of experiments.

Relation between PI and IBL

While implementing the unit in her two classes, the teacher did her practitioner inquiry (PI), posing a research question:

> *To what extent does the use of IBL method affect the test results of the first-grade high-school students working on topics related to weight, weightlessness, motion in gravitational field and centrifugal force?*

Teacher, having only two classes used both formats of the lesson: IBL and traditional in different order for both classes. Thus the humanistic class was an experimental class working with IBL method on topics: 1) centrifugal force and (3) weight and weightlessness, while it was a control class when working on (2) free motion in a gravitational field. At the same time the biochemical class was an experimental class working with use of the IBL method on topics: (2) free motion in gravitational field and (3) weight and weightlessness and it was a control class when working on 1) centrifugal force. Both classes had very much similar results in physics prior to intervention and both followed the program in which only one lesson of physics per week is planned. Before implementation most of the students admitted that the best way for them to learn physics is to listen to the teacher and copy the note formulated and given by the teachers at the end of the lesson. Less than 20% were convinced that it is possible to learn while doing experiments. This picture totally changed after intervention – students not only realized that IBL tremendously influences their understanding of physics topics, but also admitted that this method raises very much their positive attitude towards physics. In addition, the vast majority of them like doing experiments in collaboration with others and want more IBL lessons in the future. Also the results of the final tests clearly showed that both classes performed much better than the control group, if they worked in IBL format on particular topics. Independently of the class and topic, traditional methods of teaching resulted in worse results.

Teacher's Learnings

Despite the initial reserve towards classes in which students do experiments and students' prior opinion that the best way to learn physics is to listen to the teacher and copy the notes formulated by the teacher, students' attitude changed tremendously after the implementation of the IBL method. It is very much important that students realized that also their test results were better if they learned particular topics , while performing experiments in groups.

In such non - major physics classes the implementation of the IBL must start with structure or semi-guided inquiry, but even working with students at the basic level of inquiry increases their understanding of physics phenomena and their motivation towards physics. Thus I gained much more satisfaction as well.

2.3.12

Leaking bottle: which water jet is the longest?

Uroš Medar, SI

Context and goals

The activity was organized for students as they have shown great interest in IBL. So I tried to teach through IBL as much as possible. My first goal was to try and see if there is any difference in understanding the concept of hydrostatic pressure if presented through IBL in comparison with previous years, when I taught hydrostatic pressure traditionally. The second goal was to see how well they can perform an open IBL without a worksheet prepared in advance, only on the basis of knowledge they acquired during the school year.

The unit was developed by Uroš Medar, a physics teacher at Primary school Preska, Slovenia.

IBL LEVEL	OPEN
AGE & SCHOOL TYPE	• Pupils' age: 13 • Primary school
GROUPING	• 4–5 students per group • 3 classes participating in implementation • mixed-gender classes • ability-groups: random • formed by students themselves • classroom space arrangement: rows, individual desks
IBL unit resources	teacher's own material
Key concepts	Hydrostatic pressure
Inquiry skills developed	• generation ideas in discussion, • elaborating research questions • planning investigation, • developing hypothesis, • forming coherent arguments, • working collaboratively, • data gathering skills, • data analysis skills, • drawing conclusions, • presentation of the results
Scientific reasoning	• identification of variables, • problem-solving, • making comparisons.
Scientific literacy	• understanding the properties of physical quantities, • scientific explanation of concepts (use of scientific expressions), • scientific explanation of phenomena,
Assessment	**Formative**: questions leading the observation

Unit description

Hydrostatic pressure is usually presented with a bottle that has holes in it. One pours in water and then removes the plugs to see how the water runs out of the bottle. When hydrostatic pressure is presented in such a way, we point out the difference in lengths of the water jets and try to build the concept that the height of the water tower above the hole affects the length of the water jet and consequently, the hydrostatic pressure.

However, one has to be cautious where to place the bottle. It can be placed on the ground (Fig. 1) or it can be lifted from the ground (Fig. 2). There are two circumstances that affect the length of the water jet: the height of the water tower above the hole, and the height of the hole above the ground, where the jet lands. If the bottle is lifted from the ground, it is not possible to show the second variable that affects the length of the water jets, because the lowest water jet is always the longest. This is not a problem if the goal is to present the effect of the hydrostatic pressure on the length of the water jet.

Fig. 1: Bottle placed on the ground.

Fig. 2: Bottle lifted from the ground.

At the beginning of this activity, I showed my students a bottle with holes in it as shown in the picture (Fig. 3). Pupils had a good look at the bottle and they had to tell me what they would inquire about this bottle. After they decided on their inquiries, they had to form inquiry questions (IQ). These were their IQs:

- How does the height of the water affect the length of the water jet?
- How does the height of the water affect the shape of the water jet?
- How does the number of holes affect the time to empty the bottle?
- How does the shape of the bottle affect the length of the water jet?
- How does the density/viscosity of the liquid affect the time to empty the bottle?

After the debate about inquiries I prepared bottles according to their inquiries. In the next lesson students performed their IBLs and tested out their hypothesis. If students would not have their own ideas, I would try to encourage them to observe how water would run out from the bottle. But as my pupils had experience with IBLs this was not a case. Inquiries were performed in groups. Pupils formed groups by themselves.

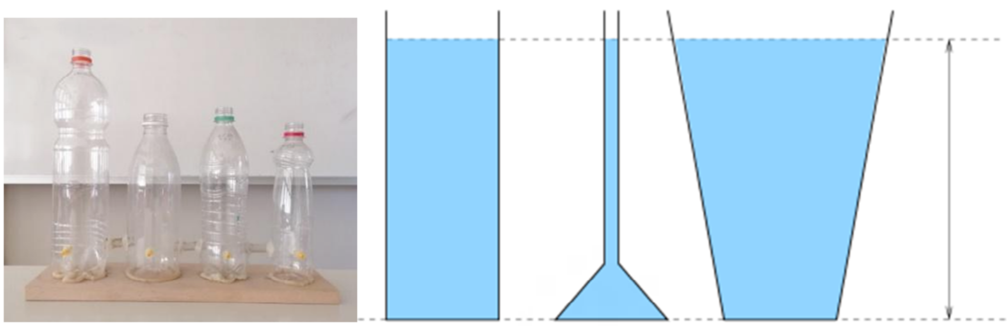
This was the first IBL they were not given a worksheet for their IBL but they had to follow the steps, goals and criteria that we set at the beginning of the year1. So pupils had to:

- define the variables for their IBL,
- write an inquiry question,
- write a hypothesis,
- design their own experiment (I constructed the supplies),
- test their hypothesis,
- analyze and interpret the results,
- write a report,
- present their evidence to their classmates,
- and solve a knowledge test on hydrostatic pressure.

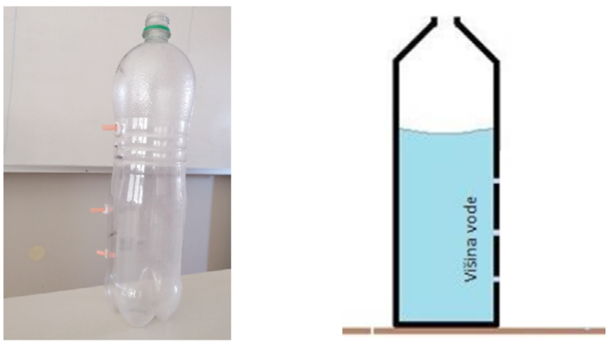
Pupils had to be careful performing these investigations, because they did not know how long the water jets would be. So they used trays to catch the running water.
After the presentations we summarized all the IBLs and determined the two quantities that affected the length of the water jet.
Hearing their presentations I got the idea that we had to develop the skill of presenting evidence and conclusions to their classmates. Next year we will put our focus on reporting.
When I started to compose the content knowledge test, I inserted in it the pictures of the experiments. Afterwards I started thinking if putting in pictures or sketches instead of photographs of the experiment would in any way impair the students' knowledge. So I prepared two different content knowledge tests to be taken by students - one test with sketches and the other one with photographs of the real experiments performed in our classes.

Assessment methods incorporated into IBL

1. The picture represents how the water jet is affected. What variable are they related to?



2. Does the shape of the bottle affect the hydrostatic pressure?
3. Draw the shape of the water jets if the bottle is full of water.



4. How does the height of the water tower affect the length of the water jet?
5. Which two physical quantities affect the length of the hydrostatic pressure?

Relation between PI and IBL

At first the activity was planned to see if pupils understand the concept of hydrostatic pressure better if they carried out an IBL, compared to classic teaching with demonstrations only. But as the activity evolved, I started thinking and started wondering how important are the presentations of the experiments they performed.

So I did a quick practitioner inquiry (PI) on the illustrations of discussed phenomena given in the concept knowledge tests. One group of pupils got sketches of the experiments and the other got photographs of the experiments they performed. My inquiry was to see if the difference in the pictures given would affect the results of the content knowledge test. So I prepared the same content knowledge test for both classes and the only difference was in the type of inserted pictures.

Teacher's Learnings

The first surprise for me was how creative the students were. One group actually thought about testing how viscosity affects the time it takes to empty the bottle. They found out, they did not know how to measure viscosity so they measured density instead. Other pupils, even those with very low level of the content knowledge in physics, also gave good ideas on their own inquiries.

Secondly, the most important from my professional point of view, was that students really struggled with sketches. I did a small PI during this lesson. I wanted to learn how sketches/photographs affect the result of a content knowledge test. The results were shocking. General success was 20 % higher where pupils had photographs of the experiments compared to those who got only sketches.

Thirdly, I noticed how well pupils caught the concept of pressure. The deeper you go, the greater the pressure. Even more, pupils would forge the results of the test just to satisfy this theory. But as we know, if the bottle is not elevated the longest water jet is the one that is the closest to the middle of the height of the water tower above the ground where a jet lands. The results of the groups with the photographs were very good – 61 % of pupils gave the correct answers. Students who were given the test with sketches did not give a single correct answer.

The final conclusion was that most pupils (64 %) solving the test with the photographs knew which two physical quantities affect the hydrostatic pressure. Much lower performance (only 41 %on average) was evidenced in a group of students solving the tests with sketches. The interesting thing was that pupils that got the test with sketches had, in general, much better grades in physics and better understanding of physical concepts. When comparing the results on the question whether students knew at least one physical quantity, I got a similar result. As much as 89 % of those who took the test with photos and only 47 % of those who took the test with sketches knew at least one physical quantity. This result may seem not as good as predicted but when I compared it to previous years it is on average still almost 10 % higher, where you have to bear in mind that students abilities were the same as in previous years.

Further reading

Medar Uroš (2020), Teaching IBL with a plan, 3DIPhE project, Volume 2.

Measurement in Physics by using IBL

Fiona Kelly, IE

Context and goals

The unit was developed by Fiona Kelly, a Science teacher from Ireland.

IBL LEVEL	Guided
AGE & SCHOOL TYPE	• 13-14 • Lower Secondary
GROUPING	• The activities were completed over 2 classes. • Grouping was made by the teacher based on mixed ability grouping in pairs for the first class and then mixed ability groups of 4 for the next two classes.
IBL unit resources	Teacher's own material
Key concepts	Measurement in physics, density
Inquiry skills developed	• planning investigation • working collaboratively • data gathering skills • generating ideas in discussion
Scientific reasoning	• classifications (of substances) • choosing right components
Scientific literacy	• understanding the properties of physical quantities
Assessment	**Formative**: Teacher diagnostics assessment, classroom dialogue, worksheets

Unit description

Before this unit, the students completed three class units on measurement, focusing on volume and mass. This unit presented consists of two lessons focused on measuring volume and mass.

In the first lesson students were given a worksheet (as below) to go through. The classroom was set up in stations. Each desk contained a station with an object to be measured i.e. a bag of sugar. I had a table at the top of the classroom with all the different measuring tools available from the science lab i.e. Ruler, string, opisometer, Vernier calipers etc. The students were then put in pairs and asked to work through the stations. They had to fill out the worksheet as they went along. A class discussion was had to wrap up the lesson and they wrote a one-minute paper, i.e. I gave each student one minute to write down as much as they could about what they learned in the lesson. Before leaving the class the students completed a Socrative quiz.

In the second lesson, I gave them another worksheet. They were focusing on the difference between volume and mass in this lesson. They had to work in groups of 4 (pre assigned by the teacher). They were given three objects each, a few pieces of metal, a Styrofoam ball and a ball of playdough. They were asked to order them in terms of how much space they took up, from the least space to most space. Then they were asked to put them in order of what their masses were. They were provided with electronic balances for this. There were other activities on the worksheet that the students worked through at their own groups pace. Then they had to come up with their own definition for mass and volume. This lesson tied density to the unit of learning. In their pre assigned groups of 4 I gave them all of the tools they needed to come up with the mass of the rock and allowed them to experiment. I did tell them the equation for density at the beginning. Any groups that were struggling I showed them a quick video which briefly described density. They then had to write up the experiment in their experiment copies. A class discussion was initiated by the teacher trying to tie in the importance of measurement, the link between volume, mass and density and also any misconceptions they had before that was now cleared up as a result of these activities.

Relation between PI and IBL

While implementing the unit in her two classes, the teacher did her practitioner inquiry (PI), posing a research question:

> *To what extent does Inquiry based learning (IBL) help students with Special Educational Needs (SEN) achieve the learning intentions in Physical World 1 & 2 in Junior Cycle Science?*

Teacher's Learnings

I found a marked improvement in student engagement. All of the SEN students fully completed worksheets during the lessons. Along with this, any homework that I gave was fully completed in their journal. I also noticed a difference in students' ownership of their learning. One student researched the name and function of the opisometer. After they did this they presented this information to the whole class. Engaging in this unit also improved students' retention of what they learned. One student was informally questioned in the following months after this lesson. The student remembered the name of all the measuring apparatus which was not the case in other topics where IBL was not used.

There are some things that I have learned through this process that I would influence my practice if going through this process again. If I was to do some similar research again I would be conscious of diagnostically assessing the students prior to the actual lesson happening rather than on the day, so that the class was pitched at the correct level while engaging the SEN students but also challenging those students that found some of this content quite easy. This was particularly the case in the first lesson which was focused solely on measurement which I know from talking to the students throughout the class that they knew most of the measuring apparatus and also what and how they were used.

This process has also allowed me to reflect on my use of IBL. IBL is a very valuable tool in the science classroom and it clearly helps students to become more curious and engaged in lessons. I just need to be conscious of the fact that it needs to be used in a meaningful way and have a very clear purpose for it to work. This investigation has taught me that although I was concentrating on students with SEN IBL can be very beneficial for high achieving students when it is implemented in the correct manner.

Supporting material

Example of Worksheet used in first lesson

2.3.14

The Moon - the Earth's companion

Małgorzata Szymura, PL

Context and goals

The unit was developed by Małgorzata Szymura, a physics teacher from Poland.

IBL LEVEL	GUIDED
AGE & SCHOOL TYPE	• 16yo • Co-ed. high school • one class (14 girls, 4 boys)
GROUPING	• 3 pupils per group • mixed-gender (however girls were the majority) • random ability groups • groups formed by students
IBL unit resources	Teacher's own material and idea
Key concepts	• the Moon's orbital and rotational motion and their consequences • The phenomena of Solar and Lunar eclipses
Inquiry skills developed	• planning investigation • developing hypothesis • forming coherent arguments, • collaborative work • data collection • data analysis • drawing conclusions • presentations of the results
Scientific reasoning	• identification of variables • making scientific connections • solving problems • making comparisons • identification (of light sources)
Scientific literacy	• reviewing prior knowledge • scientific explanation of concepts (use of scientific expressions) • modeling of phenomena, • understanding of physical quantities • understanding the real world context of the topic
Assessment	**Formative**: class observation, worksheets **Summative**: test

Unit description

1. **Brainstorming** (what do we know about the Moon?).
2. **Formulation of inquiry questions** – ideas by students (what would they like to investigate) from all groups, focus on clarified questions manageable to study experimentally during the lesson
    - Why do we see the Moon in different phases?
    - Why do we see only one side of the Moon?
    - In what situations Solar and Lunar eclipses occur?
3. **Planning and carrying out experiments**:
with the use of materials provided by the teacher (e.g. small and large polystyrene balls on skewers or grapefruit and a ping-pong ball on sticks and a steroid pad for sticking the sticks in)
4. **Presentation of the results** and **discussion between groups** about them (what results did the groups obtain?, what can be improved?, etc.)
5. Joint **formulation** of common **conclusions**.

Fig. 1 Modelling the solar eclipse

Notes

I implemented the IBL module to the group of the general secondary school students of the first grade. These students did not choose physics at the advanced level because they attended humanistic and biological-chemical classes. They did the basic physics course, 1 hour a week only until the end of the first grade. That's why I decided to try to show them how to teach and learn physics in a different way - discovering it on your own. The group was embraced by a pedagogical innovation, which assumed that every fourth lesson would be conducted using the IBL method.

In this way, I was able to implement altogether three topics from the core curriculum:

1. The Moon – the Earth's companion

2. Centripetal force

3. Radiation of bodies

Relation between PI and IBL

While implementing the unit in her three classes, the teacher did her practitioner inquiry (PI), posing the following PI question:

> *What is the student's attitude towards the IBL method?*

During the IBL lessons implementation I could see that students were very committed to doing inquiry, so it was natural for me to ask for their opinion about the IBL method. What I found out after the first implementation was not as obvious and contrary to what I had suspected. Despite the fact that the students actively and willingly participated in the classes, they did not feel that they were learning something. The first part of my PI helped me realize that my students perceive IBL lessons as having fun and not a good method of learning.

However after a long discussion in PLCT, I decided to continue an IBL lesson repetitively every four weeks and over a school year I observed a tremendous change in students' opinions about the purpose and effectiveness of learning through IBL.

Teacher′s Learnings

I realized that every time I start with IBL, I have to introduce students to the method gradually, talk to them, diagnose their needs and definitely not give up after the first examination. If students are not used to this method, they may be very distrustful and unsure of what they are learning. At first, the method looks just like fun and play, and in the traditional school system with the most common method of memorizing facts and laws, "play" is a waste of time. This opinion is also in the minds of students. Only persistence in applying the IBL method can convince students that they learn more with IBL than with the traditional format. The method itself is so addictive and interesting that sooner or later students realize that they are learning a lot.

Supporting material

Additional material available:

- Student worksheet docx
- Student worksheet pdf

2.3.15

Paper planes

Arne Van Assche, BE

Context and goals

The unit was developed by Arne Van Assche, a science and maths teacher from Meldert, Belgium.

IBL LEVEL	Structured, partially guided
AGE & SCHOOL TYPE	12 yo
GROUPING	Groups of 3
IBL unit resources	Booklet RVO; In-service training RVO; Adapted version here.
Key concepts	pitch and directional stability of a flying plane
Inquiry skills developed	• generating ideas in discussion • working collaboratively • data gathering skills • drawing conclusions
Scientific reasoning	• identification of variables • choosing right components (materials, devices) • making comparisons
Scientific literacy	• reviewing prior knowledge • understanding the properties of physical quantities • searching for information in external sources • understanding the real world context of the topic • understanding of physical quantities • evaluate and design scientific investigation
Assessment	**Formative**: self assessment of 3 planes, choosing the best; self assessment, comparing the new, improved plane with the old one.

Unit description

1. The history of flying illustrates the **real world context of this topic**.
2. Challenge: each pupil in the group builds his/her own paper plane,using their **prior knowledge** and then they **gather data** on time and distance the planes fly.
3. By **making comparisons** they choose the best plane out of 3.
4. Then the pupils get some information about pitch and directional stability of a flying plane and are ask to **search for information in external sources**.

5. Then they work out **collaboratively** a sketch for a paper plane that has better properties, showing that they **understand of physical quantities** pitch and directional stability.
6. Then they decided on **choosing the right paper and the best folding method.**
7. Then the improved plane is folded and again they **gather data, and compare the new data** with the old ones.
8. They **draw conclusions**.
9. Finally they reflect and **evaluate their new design**.

Notes.

This module is rather small, but still tackles several elements of IBL. It is also ready for further adaptation (if time is available):

- more stress on argumentation
- competition between groups, and peer assessment, peer feedback too
- searching for the world record distance with a paper plane
- correlation between time and distance… are both valid or is one parameter giving basically all information? Are there planes that win when distance is taken and loose when time is taken, or vice versa? how to combine both?
- an additional inquiry can be to build the same plane with different kinds of papers and let pupils conclude themselves which one is best.
- let students also make a glider with styrofoam, using the principles they learned

Relation between PI and IBL

This module was given first in a traditional way, extremely structured. The teacher was very unhappy because the results were poor, and the timing was a disaster.
After feedback of peers he adapted his unit. This time the teacher had a small preliminary inquiry on this 2 hr unit, asking himself:

- *How do students evaluate and improve their own aircraft?*
- *How can the timing contribute to a better focus on the research question?*

He went through the module with the pupils, giving them more freedom during the work with the paper planes, however trying not to lose time by imposing a strict timing. At the same time he still provided scientific input in several phases, forcing pupils to consider the theory in making a better plane.
Pupils claimed they could improve their paper planes, the collaborative work was considered useful and the timing was perceived rather positive, leading them to real results in the given time.

Supporting material

Additional material available:

- student worksheet

2.3.16

Spectroscope

Beata Sobocińska, PL

Context and goals

The unit was developed by Beata Sobocińska, a science teacher from Poland.

IBL LEVEL	STRUCTURED/GUIDED
AGE & SCHOOL TYPE	• 16yo • High school • One class, 29 students
GROUPING	• 4 pupils per group • Six groups: 1 (girls), 3 (boys), 2 (mixed gender) • random ability groups • groups formed by students, having in mind the gender structured planned by teacher
IBL unit resources	Teacher's own material (adaptation of the Rainbow in a box) Teacher's own presentation From Sun to electric bulb Worksheets adjusted by teacher
Key concepts	Energy, spectra
Inquiry skills developed	• developing hypothesis • forming coherent arguments • planning investigation • working collaboratively • ability to take notes • data analysis • drawing conclusions, • presentation of the results
Scientific reasoning	• identification of variables • selection of appropriate materials • problem solving • making comparisons • identification of light sources on the basis of spectra
Scientific literacy	• identification of the consequences of human interference in the environment • use of scientific expressions • searching for information in external resources • scientific explanation of phenomena • understanding of physical quantities • understanding of the real world context of the topic • construction of spectrometers from everyday materials
Assessment	**Formative**: observation of the group work; quiz on energy; rubrics on scientific reasoning and on scientific argumentation; student self-assessment and peer-assessment

Unit description

The IBL unit on spectrometer was implemented during three lessons being a part of the module on Energy in science course. Teacher implemented IBL in one class and did the same module traditionally in another (control) class.

1. Division into groups; students formed the groups of four by themselves with regard to the teacher requirement of gender structure of groups.
2. **Brainstorming** on the context: light and energy sources, nature of light, spectra in everyday life.
3. Teacher presentation on light and spectra
4. Getting familiar with instructions on how to build the spectrometer from everyday materials.
5. **Formulation** of possible **inquiry problems** and questions in groups.
6. **Construction of spectrometers**
7. **Planning the experiment** in groups.
8. Taking notes on the basis of experiment (notes guided by a worksheet).
9. **Analysis of the results** in groups.
10. During the group work and after collecting the worksheets with students' notes, the teacher evaluated each student with the use of **rubrics**.
11. **Presentation of the results** to other groups.
12. **Peer- and self-assessment** by individual students.

Fig. 1 Collaborative work of students during building spectrometers and researching the sources of light with use of their spectra

Relation between PI and IBL

While implementing the unit in her three classes, the teacher did her practitioner inquiry (PI), posing two research questions:

1. *To what extent is the IBL method effective in teaching physics as one of the science lesson modules in the second grade of high school?*
2. *How does the gender structure of students in the group affect the effectiveness of IBL teaching in science lessons?*

Comparing the results obtained by the class learning the IBL method to the results obtained in the class learning traditionally – the results in the experimental group were much higher as regarding the content knowledge related to the experiment. Teacher also found in the experimental class some differences determined by the gender structure of the groups. The best results were obtained by boys and mixed groups. This may suggest the influence of the male element among the group of girls, which increases their learning performance in a subject usually liked more by boys than girls. At the same time, it was observed that in the phase of planning and carrying out the experiment itself, the groups of girls were more creative, which may again be associated with their greater ability of multitasking, as well as attentiveness and diligence. To sum up, it is reasonable to conduct classes using the IBL method in mixed groups, as it often gives better results. This problem should be researched further because the research group was too small to generalize such conclusions to the entire population. However, it is worth asking constantly questions in the teacher's work that stimulate the teaching process and make it more attractive and more effective for both the students and the teacher.

Teacher's Learnings

1. *It is worth conducting lessons using the IBL method, because it develops creativity in students, facilitates understanding of the subject matter in context, and encourages students to be active and learn how to do scientific inquiry. At the same time, it brings better learning outcomes.*
2. *It is worth experimenting with the structure of student groups, mixing them in a way that allows the best use of the student's potential.*
3. *Peer- and self-assessment were inconsistent with each other. The results showed that students performing the best are the most critical towards themselves and on the other hand those scored least are the most self-confident and evaluate their own work very high. So the conclusion is that peer- and self-assessment tools should be used more frequently during classes in order to develop the honest and clear view of their work and engagement in students.*

Synthesize the Timbre of Your Preferred Instrument - Music and Science

Jordy Zwaenepoel & Tessa Jacobs, BE

Context and goals

The unit was developed by Jordy Zwaenepoel and Tessa Jacobs together with a group of colleagues. They both are secondary physics teachers from Belgium.

IBL LEVEL	Guided
AGE & SCHOOL TYPE	• 14-16 years old • Technical Upper Secondary school
GROUPING	• 3 students per IBL-group, total of 1 class (10 students) • Mixed-gender • 6 x 50 minute lessons • Heterogeneous with respect to the student level • Formed: by teacher • Classroom: rows
IBL unit resources	Material adapted based on teacher's involvement in iMuscica and informed by peer discussion during 3DIPhE sessions.
Key concepts	Sound, tone, waves, frequency, spectrum, harmonics, upper tones, musical instruments, timbre
Inquiry skills developed	• planning investigation • developing hypothesis • forming coherent arguments • working collaboratively • data analysis • drawing conclusions • presentation of the results
Scientific reasoning	• problem solving • identification of variables • making scientific connections • proportional reasoning • making comparisons
Scientific literacy	• understanding the properties of physical quantities • evaluate and design scientific investigation • presentation of scientific data (graphs, tables) • scientific explanation of concepts (use of scientific expressions) • scientific explanation of phenomena
Assessment	**Formative**: The in between short presentations of the findings after every inquiry question. **Summative**: The final presentation on how they made their own synthesized timbre.

Unit description

The focus of this lesson was to develop students' **conceptual understanding** of the physics behind music. Therefore they've got the **challenge**: synthesize the timbre of your preferred musical instrument.

By **experience** they listened to different instruments and recognized that you could differentiate them on the basis of their typical tone colour. How can we understand this phenomenon? They measured the waveforms of the different instruments and discovered that it is the waveform that differs even when a tone of the same pitch is played. By **measuring** the sound spectrum they can discover that there are many frequencies hiding behind the ground pitch. The discovery of the harmonics (partials) is the key to the scientific understanding of timbre. They **investigate** the difference in strength (amplitude) of the different partials. This gives them the starting point to start synthesizing instruments. They **analyse** the timbre of their chosen instrument and start synthesizing the tone colour of it.

The whole process is guided by a worksheet with some structure and **guiding questions** on.

1. **Context**: Can you recognize different instruments by listening to them?
2. **Problem**: Can we scientifically understand why 2 instruments sound different even though they play the same tone?
3. Do we measure the same frequency (s) when playing a tone on 2 different musical instruments?
4. **Hypothesis**: How do we **explain** that the same tone sounds different on one instrument compared to the other instrument?
5. **Data gathering & analysis**: Does the relative strength of the different frequencies affect the waveform of the produced tone?
6. **Forming coherent arguments**:
   Can we synthesize, on the other hand, a particular timbre of an instrument?
7. **Explanation with use of scientific concepts: Conclusions, presentation**

Collaborative learning: for each **inquiry question** the student group had to investigate **in groups** the **given problem**. After every of those little inquiries, they **present their findings in confrontation with the other groups.** Every group ends the whole inquiry process by presenting the synthesized sound of their preferred instrument and to **explain** how they reached this point.

Following the inquiry activities, students completed a post questionnaire. This had a similar format to the pre-questionnaire in that they had to mix and match terms to descriptors. However, an extension of the worksheet required that students now provide justification and reasoning for their answers.

Relation between PI and IBL

The aim of the related PI was to investigate whether or not students are more motivated for physics if the physical concepts of waves, frequencies etc. are investigated in this rich interdisciplinary context of physics with music. The PI research question was:

Does adding Music to Science result in extra motivation for Science?

Teacher's Learnings

- Learners often think that physics is difficult. Learners are more enthusiastic to present results if they do not only talk about physics, but about something like music as well. It seems to help the students to bring the abstract physical concepts to life.
- It seems to be that the input of music on top of physics helps to stimulate the deeper learning and motivation for physics as well.
- To use the context of music, the teacher has to have a good knowledge of music as well or – and this is even more fruitful- has to cooperate with the music teacher for this course. Also some musical activities were incorporated in the lessons. These turned out to be very fruitful for both subjects.
- In any way the students (and the teacher!) were quite enthusiastic about this IBL in physics and music.

PART C:
Developing IBL Teaching Skills

CHAPTER 1:
Workshops for Developing IBL Teaching Skills

CHAPTER 1:
Workshops for Developing IBL Teaching Skills

1.1 INTRODUCTION

Education through inquiry involves active engagement of all actors, not only students, but also teachers, who design the IBL lessons and support students during the implementation. The best IBL examples from coaches and PLCT teachers provided in Part 2 of this volume give a good base for enhancing IBL teaching skills. By implementing the examples in their own classes, teachers can practice the IBL method principles, develop their positive attitude towards the IBL and their self-confidence in conducting the IBL cycle in an accurate manner. Following the examples they can adapt the existing IBL learning materials to the specific curricula or the needs of their students. However, such a path enables teachers, in a sense, to come only halfway to developing their sense of ownership in teaching the IBL. During the course of the 3DIPHE project it occurred that in order to master their competences in the IBL method teachers need to experience the IBL spirit in a more rigorous, deepened approach to the method.

Teaching with use of an active method demands from teachers open-mindedness, flexibility and readiness to leave their comfort zone of copying and adapting the learning units provided by coaches or available from different resources. They need to start to create the IBL material by themselves from scratch. However they should not be left alone in this process, since that might result in many doubts, early-stage discouragement and dropping the demanding IBL method. Teachers should be rather supported by other teachers, making preferably the same journey of developing the IBL teaching skills. Such an opportunity arises in Professional Learning Communities of Teachers (PLCTs), described in detail in Volume 2.

In what follows, a proposal for workshops on developing IBL Teaching skills is presented on the basis of our experience with IBL implementation in PLCTs in 3DIPhE project.

1.2. WORKSHOP FORMATS AND TIMELINE

Workshops with PLCTs are mainly devoted to the development of PLCTs as communities of cooperating professionals, supporting each other in identifying and discussing common issues related to their teaching practice. As part of such workshops PLCTs may also acquire or develop particular skills in using certain strategies of teaching, such as IBL.

Two approaches to introducing and developing the IBL teaching skills are proposed. The first is intended for teachers with very little or no experience in teaching through IBL. For them the introduction to the IBL method is necessary, based on a sequence of intensive activities in exploring existing IBL materials. During a few workshop meetings teachers take on the roles of students and experience the IBL activities, following the material introduced by the coach. Subsequently, the teachers start the second sequence of workshops in an advanced format. Preferably, teachers start their pilot implementations of the IBL method in their class somewhen between the first, introductory part of the course and the second, advanced part. In such a way they gain experience from two perspectives, which is beneficial for their development when they start workshops at the advanced level. Teachers already experienced in the IBL method may deepen their practice by participating only in the advanced part.

During the advanced sequence of workshops teachers take part in two types of activities. They continue their experience of the ready-to-use IBL learning units during the workshops when they again take on the roles of students. At the same time, during each meeting they also participate in workshops, in which they practice one particular IBL teaching skill at a time, playing alternately the roles of teachers - unit designers and the roles of students. For that they follow the protocols attached in Appendix 3. Timelines for both approaches are presented in Fig. 1.

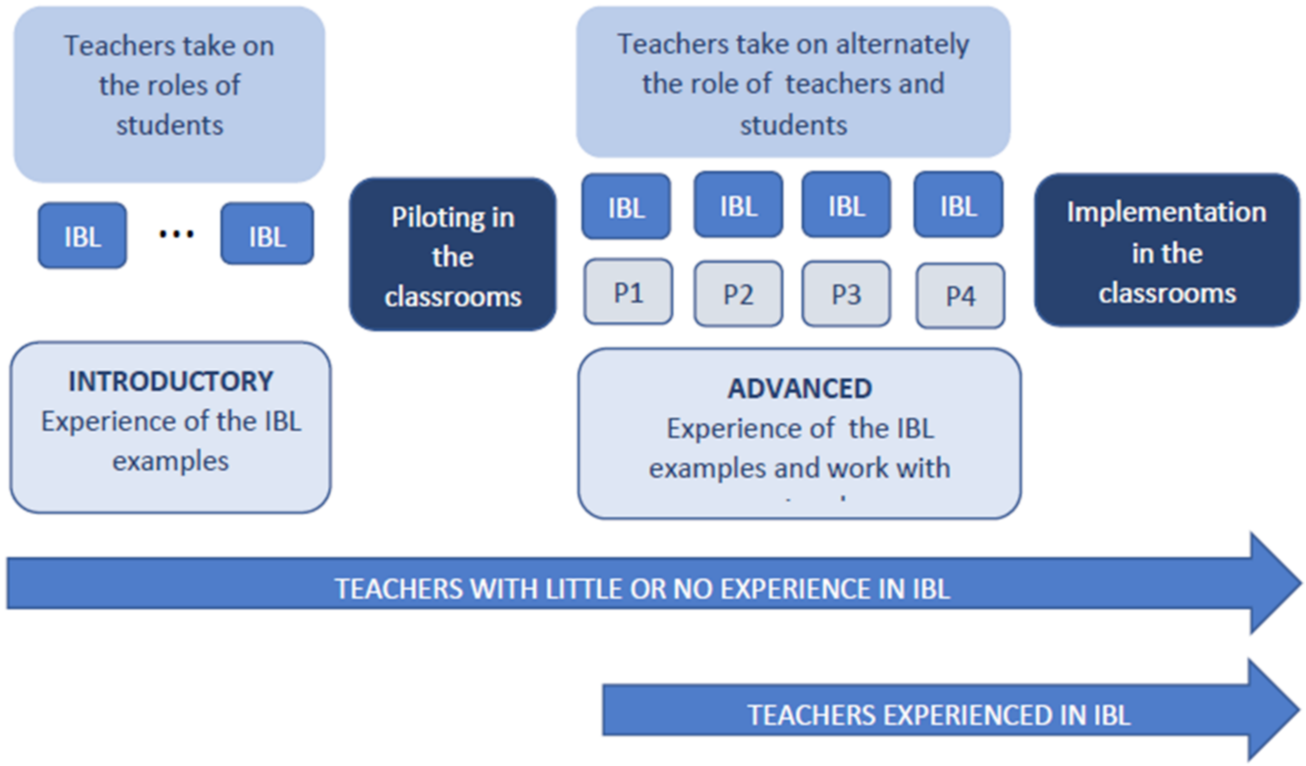


Fig. 1. Timelines of two sequences of the course for developing the IBL teaching skills. **IBL** boxes indicate workshops for experiencing ready-to-use IBL learning units, provided by coaches. **P1-P4** boxes indicate workshops on developing one particular IBL teaching skill at a time.

Introductory workshop meetings usually last 2-3 hours each and extend over a span of a few weeks or even months, depending on teachers' needs and development of their self-confidence in IBL. The sequence might be preceded by a short theoretical introduction to the IBL method background, the IBL cycle and different IBL levels of implementation (see Volume 1, Part 1). During the introductory part, it is very important to recall from time to time the general aspects of the IBL method, its principles and the "philosophy" driving the method. The ready-to-use IBL units, implemented during the introductory workshops, are available in Volume 1 Part 2 and on the webpages of many EU projects, among others: ESTABLISH[1] and SAILS[2]. Depending on the circumstances, they can be used as designed, as well as be shortened, expanded or adapted to teachers' own purposes. It is the role of a coach to design the sequence of the introductory workshops in the manner most suitable for the certain PLCT members and their needs. Usually, the units selected for the first meetings relate to the structured level of IBL and over time the guided inquiry learning units are introduced. At the end of the sequence the use of open inquiry activities is recommended. However, it might also happen that the very first unit, launching the introductory sequence will be totally open, just to make teachers fully engage and sense the "philosophy" behind the IBL method.

[1] ESTABLISH Project EU, http://www.establish-fp7.eu/project.html
[2] SAILS Project EU, http://www.sails-project.eu/

The advanced part of workshops spans 4-5 meetings. In the course of the advanced sequence the teachers continue with more demanding ready-to-use IBL learning units, selected by the coach. This part of each meeting lasts usually maximum two hours. The second half of each meeting in the advanced part is devoted to practicing one IBL teaching skill at the time. Teachers working in a group of three or four design a particular part of the IBL learning unit and later on they implement this material in the second group of teachers who play the role of students. Later the groups change their roles and the second group implements its material in the first one. Groups of teachers work in a rigorous, structured way, implementing the protocols (see Appendix 3). The protocols set teachers' roles, time for the activity and the steps to complete. Teachers work independently, without interference of a coach, however if the coach realizes that more time is needed for the completion of the particular protocol activity, s/he should propose the teachers the extension of the time span.

IBL Protocol 1

The first step in such an approach is to ask the teachers to lead the brainstorming around a certain topic (IBL Protocol 1). During the 3DIPhE project it turned out that even teachers who declared that they had already conducted lessons in the IBL method, might have problems with the proper start of the IBL cycle. Asking students the right questions and being a good leader during the brainstorming could be a crucial step influencing the process of the next steps in the entire IBL cycle.

In the 3DIPhE implementation we observed that by playing the role of a teacher and a student alternately, teachers not only gained a lot of inspiration and shared their experiences from schools at various levels, but also had a great time. They experienced how hard it was to lead a vivid discussion, but at the same time they admitted that going through it together encouraged them to try to implement the IBL initial brainstorming in their classes.

IBL Protocol 2

In the second meeting at the advanced level teachers practice formulating the IBL research question. Groups can continue with the subject topic chosen at a meeting before for practicing the conducting of the brainstorming or they can concentrate on another topic.

In the 3DIPhE workshops it occurred that teachers easily set up one relevant IBL research question, related to one IBL level. However, PLCT members usually had problems in formulating three different questions regarding three different levels, and only working collaboratively, they could come up with a complete set of three questions. Some teachers also had initial difficulties in understanding and fulfilling the demand that the research question needed to be formulated in such way, that the answer to it would not be simply "yes" or "no".

IBL Protocol 3

In the third meeting teachers are supposed to design one IBL learning unit plan. For that they follow the IBL Protocol 3. Teachers need to remember that when they plan experiments with students the care of a fair test should be taken. Students are usually aware of it, but sometimes it is inevitable that they would like to change different parameters at the same time. Planning an investigation in the IBL process is often the most difficult part for students. And it is worth to notice that an ill-considered experiment can lead to chaos and discouragement.

In the 3DIPhE implementation it was observed that teachers had problems with considering students' independence when designing the part in which students were supposed to plan and perform the experiments. Teachers had a lot of doubts about experiments done solely by students, and were concerned about the content knowledge acquired during the IBL lessons. An additional problem pointed out was the time allocation for the unit implementation in the classroom and curriculum demands. Teachers pointed out that they did not have the suitable equipment at school. While discussing the design of IBL experiments, the coaches may try to propose simple solutions that do not require the use of special lab equipment and materials and may give hints how to replace them by tools and materials from everyday life .

After this session PLCT teachers from the 3DIPhE project admitted that usually they had taken ready-to-use IBL modules and implemented them in their classes without much reflection on particular IBL steps. However they agreed that mastering in IBL teaching should go through a procedure of the design of each part of the IBL learning unit, preferably in collaboration with other teachers. This way teachers shifted from a copy/paste mode to the authorship and thus to the teaching ownership mode.

IBL Protocol 4

The last IBL protocol relates to the design of the assessment tools tailored to the IBL method. Teachers are asked to follow the IBL protocol 4 in groups of three or four. The protocol concerns only formative assessment tools (compare, Volume 1, Part 1, sec. 3.1). Since teachers are usually not much experienced in the design of the formative assessment, more time than anticipated in the protocol can be devoted to this activity and the protocol implementation can be also done in two steps during two subsequent meetings of PLCT teachers at the advanced level.

In the 3DIPhE workshops teachers went quite smoothly through the Activity table and Self- and Peer-assessment tools. However they struggled with the design of rubrics. Only a thorough discussion with the other group members brought them to understanding of two main principles of the design of rubrics distinguishable levels, (e.g. (1) each subsequent level assumes that the criteria of the previous level are met (2) level description should be prepared with use of a clear, single criterion separating it from the other two adjacent levels) and enabled the final revision of their tools.

Self-Reflection Tool for Teachers

During the last meeting in the course of the advanced sequence of developing the IBL teaching skills, PLCT members may be asked to reflect individually on their IBL practice in their own classes. For that the Self-reflection Tool for Teachers, designed in the Fibonacci[3] project could be used (refer to Volume 1, Part 1, subsec. 3.3). The tool was designed solely for the self-reflection and, as emphasised by its designers, it *was not designed to score teachers on their teaching*[4]. This is also worth to notice that the tool *does not convey all positive features of science teaching practise, only those specific to an inquiry-based pedagogy,* as mentioned in the introduction to this tool.

Teachers experienced in the IBL, participating in the workshops on developing the IBL teaching skills at the advanced level may reflect with use of the above-mentioned-tool even twice, first, just at the beginning, and for the second time - during the last meeting. This way they may see their own progress in reinforcing their competences in teaching by inquiry.

On the basis of our long experience from workshops for PLCTs in 3DIPhE project and some other EU projects on dissemination of the IBL method, we believe that the strategy for enhancing IBL teaching skills in teachers, described above, addresses the needs and expectations of both groups of teachers, novices and those more experienced in implementation of the IBL method. This opinion is shared by teachers starting their adventure of teaching through IBL. Moreover even teachers, who thought they were a bit experienced in IBL implementation in their own classes, admitted that they really appreciated the revealing idea of going step by step throughout the entire IBL cycle with use of a series of protocols developing skills in teaching by inquiry.

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[3] Fibonacci Project, https://www.fondation-lamap.org/en/page/9546/fibonacci-a-european-project;

[4] Tools for Enhancing Inquiry in Science Education, S.B. Carulla (ed.), pp. 40-43 https://www.fondation-lamap.org/sites/default/files/upload/media/minisites/action_internationale/1-tools_for_enhancing_inquiry_in_science_education.pdf

APPENDIX

*Appendicies that are in docx and pptx format will be automatically downloaded.

APPENDIX 1 (from Coachs' IBL moduls)

1.3.1 Double shadow, Mojca Čepič, Maja Pečar and Ana Gostinčar Blagotinšek, SI

3D IBL Worksheet Double shadow UL.pdf
3D IBL Worksheet Double shadow UL.docx
3D IBL Guide Double shadow UL.pdf
3D IBL Guide Double shadow UL.docx
3D IBL Poster Inquiry guide UL.pdf

1.3.2 Friction, Dagmara Sokołowska, PL

3D IBL Worksheet Friction UJ.docx
3D IBL Worksheet Friction UJ.pdf
3D IBL Guide Friction UJ.docx
3D IBL Guide Friction UJ.pdf

1.3.3 Penumbra and the spreading shadow, Mojca Čepič, Maja Pečar and Ana Gostinčar Blagotinšek, SI

3D IBL Text Shadow terminology UL.pdf
3D IBL Text Shadow terminology UL.docx
3D IBL Guide Penumbra UL.pdf
3D IBL Guide Penumbra UL.docx
3D IBL Worksheet Penumbra UL.pdf
3D IBL Worksheet Penumbra UL.docx.
3D IBL Poster Inquiry guide UL.pdf
3D IBL Worksheet Penumbra solo UL.pdf
3D IBL Worksheet Penumbra solo UL.docx
3D IBL Worksheet Spreading shadow UL.pdf
3D IBL Worksheet Spreading shadow UL.docx

1.3.4 Plasma Spheres, Jan de Lange, BE

Presentation about plasma phenomena
Presentation about plasma (basic theoretical background)

1.3.5 Pressure, Mojca Čepič and Ana Gostinčar Blagotinšek, SI

3D IBL Worksheet Pressure UL.pdf
3D IBL Worksheet Pressure UL.docx
3D IBL Guide Pressure UL.pdf
3D IBL Guide Pressure UL.docx

1.3.6 Rainbow in a box, Dagmara Sokołowska, PL

3D IBL Worksheet Rainbow in a box UJ.docx
3D IBL Worksheet Rainbow in a box UJ.pdf
3D IBL Spectroscope construction UJ.pdf
3D IBL Guide Rainbow in a box UJ.docx
3D IBL Guide Rainbow in a box UJ.pdf
3D IBL Rainbow in a box UJ.pptx

1.3.7 Speed, Eilish McLoughlin, IE

Outline of Workshop on Speed Unit
Worksheet for Speed Unit
Assessment rubrics for Speed Unit

1.3.8 Spaghetti Bridge, Dagmara Sokołowska, PL

3D IBL Worksheet Spaghetti Bridge UJ.docx
3D IBL Worksheet Spaghetti Bridge UJ.pdf
3D IBL Guide Spaghetti Bridge UJ.docx
3D IBL Guide Spaghetti Bridge UJ.pdf
3D IBL Spaghetti Bridge UJ.pptx

1.3.9 Subtle Shifts, Jan de Lange, BE

Worksheet shifted activity
Materials for chemistry activity
Background science for chemistry activity
Worksheet responsibility student teacher
Worksheet unshifted activity
Worksheet on shadows

1.3.10 Which chocolate is the best? Ana Gostinčar Blagotinšek, SI

3D IBL Worksheet Chocolate UL.pdf
3D IBL Worksheet Chocolate UL.docx
3D IBL Guide Chocolate UL.pdf
3D IBL Guide Chocolate UL.docx

1.3.11 Generic template for the IBL unit, Ana Gostinčar Blagotinšek, Maja Pečar and Mojca Čepič, SI

3D IBL Poster Inquiry guide UL.pdf
3D IBL Worksheet Generic for students UL.docx
3D IBL Worksheet Generic for students UL.pdf
3D IBL Guide Generic for teachers UL.docx
3D IBL Guide Generic for teachers UL.pdf

APPENDIX 2 (from Teachers' IBL moduls)

2.3.5 Determining taste zones of the tongue, Guy Puttevils, BE
Student worksheet in English
Example of student worksheet (Dutch)

2.3.9 Electrical Flow, Seán Kelleher, IE
Student worksheet
Pre-test
Post-test

2.3.13 Measurement in Physics by using IBL, Fiona Kelly, IE
Example of Worksheet used in first lesson

2.3.14 The Moon - the Earth's companion, Małgorzata Szymura, PL
Student worksheet docx
Student worksheet pdf

2.3.15 Paper planes, Arne Van Assche, BE
student worksheet

APPENDIX 3 (from Part C)

IBL Protocol 1

IBL Protocol 2

IBL Protocol 3

IBL Protocol 4

Self-Reflection Tool for Teachers

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