Preliminary inquiry classroom scenarios and guidelines

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Executive Summary

This document describes an initial blueprint of how teacher and developers are, in Go-Lab, supported in creating *Inquiry learning Spaces* (ILSs) and their associated *Lesson Plans*. ILSs are the Go-Lab learning environments that include an online laboratory and the instructional guidance for students. A Go-Lab Lesson Plan includes an ILS and, in addition, a description of offline (possibly collaborative) activities that can or should be performed with the ILS. So, the Lesson Plan also describes, next to the ILS, the student and teacher offline activities. Lesson plans are based on *scenarios*. A Go-Lab scenario describes, in a *domain independent way*, all activities, materials, and interactions for teachers and learners that comprise a complete (online and offline) Go-Lab inquiry learning experience. An example of a scenario is the *Jig-saw approach*. In this scenario students perform their inquiry in groups of differing composition. Another example is the Critiquing scenario in which students learn by writing a critique on an existing experimental set-up.

In this deliverable we start by defining the basic terminology as used in the project and which is also important information for a teacher. In this terminology the concepts “scenario” and “lesson plan” are the key concepts for the current deliverable. Second, the main components of a scenario, the inquiry activities and their sequence, online and offline aspects of this and which activities are performed collaboratively or individually, are described. Third, an initial set of scenarios is given. These are: variations on the basic scenario, the jig-saw approach, changing hats, and learning by critiquing. This set will grow, also on the basis of the concrete lesson plans we will develop and which, if they have a specific new character, can lead to introducing a new scenario. Fourth, a number of concrete lesson plans, examples of how scenarios work out in practice with a specific domain and a real context, is listed. Fifth, we give a first idea of information that can be placed in a default Lesson Plan. The idea is that for each scenario a default lesson plan (so an ILS, but without the online lab, and the related offline activities) is created that can be used by teachers as a starting point for creating their own lesson plan around a chosen online lab. Finally, a proposal is presented on how teachers can learn about scenarios and lesson plans and how they can be supported in creating, adapting, and sharing ILSs and Lesson Plans.

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1 Introduction

This deliverable describes an initial blueprint of how teachers and instructional designers will be supported in selecting, adapting, and designing Inquiry Learning Spaces (ILSs). ILSs are the Go-Lab learning environments that include an online laboratory and the instructional guidance for students. The support for teachers we will develop, and of which a first structure is presented in this document, is based on a number of presumed actions that a teacher may take when preparing the use of an ILS in his[1] classroom. We foresee that a teacher's initiative most often is based on the science topic he is teaching and that different steps will follow this initial choice. These may follow different sequences and teachers may leave out certain steps as well. The presumed steps are;

1. The teacher decides on the domain/topic he wants to use an online lab for. This can be a topic of which the teacher thinks that the teaching can be improved by taking a more inquiry-based approach or the teacher can also be inspired by an online lab he has seen (for example in the Go-Lab repository). In the following steps we assume there is a suitable online lab for our teacher in Go-Lab's repository.
2. After having selected a suitable online lab the teacher most probably starts to think on how to create a pedagogical structure. For this there are several options. The first two apply when an appropriate lesson plan is found:
    a. Our teacher searches through the Go-Lab repository to see if there are lesson plans (a fully instantiated pedagogical approach for a specific domain, this means that all on-line and offline (also collaborative) activities are defined) on a) his topic and b) the pedagogical approach (scenario) he prefers. If he can find such a lesson plan he can directly offer this to his students.
    b. If there is a lesson plan available that is close to what a teacher likes but isn't fully suited for the teacher's needs, he may still select that one and adapt it to his needs. This could mean, changing (adapting or replacing) the available resources, guidance, etc. in the ILS and/or the recommended (collaborative) or off-line activities. The online lab most probably will stay unchanged.
3. Also if there is no appropriate lesson plan available, Go-Lab may still support the teacher in creating a lesson plan (including the ILS):
    a. If there is no lesson plan that can be directly used or adapted, the teacher may look through the available Go-Lab scenarios (general descriptions of different pedagogical approaches in Go-Lab) and try to find a scenario that a) he likes b) fits his educational objectives c) fits his students' prior knowledge and inquiry skills d) is organisable in his classroom.
    b. After having selected a scenario the teacher may decide to create his own lesson plan. He starts by selecting a "default lesson plan" for a specific scenario and include the online lab. Then he may continue creating an ILS from the default ILS for this scenario, adapt the available scaffolds for this domain (through the app composer) and adapt the default texts for his own class. In the "default lesson plan" the teacher will find standards texts for the different phases in the inquiry cycle and for the different types of guidance. In addition there are and all kinds of info for collaborative or off-line activities that are characteristic for the scenario that was chosen.
4. On the Go-Lab portal teachers can add new lesson plans and the "default ILSs" can be adapted and augmented after suggestions of the teacher community.

[1] We use "he" or "him" to indicate both female and male teachers

The work on Go-Lab “classroom scenarios” facilitates this process in a number of ways:

- First, it will define a set of more general pedagogical scenarios that teachers can easily browse. We will try to make this set of scenarios as small as possible in order not to overwhelm the teacher. Also, the descriptions of these scenarios should be brief so that a teacher may easily get a quick impression of the possibilities. Section 3 describes four scenarios (of which the first scenario has a number of variations). This set of scenarios will be extended in the course of the project.
- Second, we will make a large set of lesson plans available. These lesson plans can be directly used by teachers, be adapted or possibly function as a source of inspiration. Section 4 (and Annex A) currently give five lesson plans for different domains and following different scenarios. This number will be rapidly increased.
- Third, we will create default texts for ILS inquiry phases and guidance (e.g., relevant heuristics) that teachers can use as the basis for their own ILSs. Currently, a first version of these default texts is only available for the basic scenario (see Section 5). In addition for each scenario default suggestions for off-line (collaborative) activities will be given.

The build-up of this deliverable is as follows. First, we start outlining the basic terminology as used in the project and which is also important information for a teacher. In this terminology the concepts “scenario” and “lesson plan” are the key concepts for this deliverable. Second, we describe the main components of a scenario, the inquiry activities and their sequence, online and offline aspects of this and which activities are performed collaboratively or individually. Third, we describe a set of scenarios. Currently this set is still limited, there are variations on the basic scenario, the jig saw approach, changing hats, and learning by critiquing. This set will grow, also on the basis of the concrete lesson plans we will find or develop and which, if they have a specific new character, can lead to introducing a new scenario. Fourth, we present a number of concrete lesson plans, examples of how scenarios work out in practice with a specific domain and a real context. Fifth, we give a first idea of information that can be placed in the default ILS. Six, a proposal is presented on how teachers can learn about scenarios, lesson plans and how they can be supported in creating or adapting ILSs.

2 Starting points for creating pedagogical guidance for teachers

2.1 Terminology

In order to provide teachers with adequate support for using, adapting, and creating ILSs and lesson plans we need to have a clear terminology. This section defines the terminology as it is agreed upon in the Go-Lab project.

Online labs

Online labs are science labs offered through computer technology. The core activity in an online lab is an investigation (experimentation or exploration) with (physical or virtual) equipment or the possibility to work directly with the results of such an investigation (in the form of data sets). In investigation is material, physical or virtual, is manipulated in order to provide insight into the relationship between variables. Not all investigation facilities are online labs. For example, a predator-prey simulation has no (virtual) equipment and thus would not count as an online lab.

We distinguish three types of online labs:

- Remote laboratories. In a remote laboratory the investigation is performed with physical equipment that is operated on a distance
- Virtual laboratories. In a virtual laboratory the investigation is performed with simulated (virtual) equipment
- Datasets/analysis tools. Datasets are outcomes of investigations with physical or virtual equipment. Datasets often come with dedicated analysis and visualisation tools that help to organize and interpret the dataset.

Inquiry learning

Inquiry is an approach to learning that involves a process of exploration that leads to asking questions and making discoveries in the search for new understandings (based on National Science Foundation, 2000). This means that in an inquiry learning process information is not directly offered but needs to be discovered through investigation activities by learners themselves.

Guidance

Guidance is the support that helps the learner in the process of inquiry in the online lab. Guidance exists of a so-called inquiry cycle that provides the learner with a set of phases as an organization of the inquiry process. In each phase the learner can be offered the following specific forms of guidance:

- Process constraints. Process constraints aim to reduce the complexity of the inquiry learning process by restricting the number of options students need to consider (e.g., offering simplified equipment).
- Dashboard. A dashboard provides the student with a (graphical) overview of inquiry actions (e.g., number and type of variables manipulated) or product aspects (e.g., quality of a concept map).
- Prompts. Prompts are reminders or instructions to carry out a certain action or learning process.
- Heuristics. Heuristics give students general suggestions on how to perform a certain action or learning process.
- Assignments. Assignments are exercises that explain students what actions to perform.
- Scaffolds. Scaffolds are tools that help students perform a learning process by supporting the dynamics of the activities involved. An example is a scaffold is a tool that helps the learner to create an experimental design.
- Direct presentation of information. Offering of information that should have been the result of the inquiry process (but was not found by the student).

Inquiry Learning Space

An Inquiry Learning Space (ILS) is the learning environment that offers students a set of online facilities for inquiry learning following a general inquiry cycle. It includes all or a subset of:

- A specific Online Lab. One of the three, or a combination of, types of online labs with a specific domain content.
- Guidance. A (selection) of guidance facilities
- Resources. Background material in the form of texts, videos, or other means. Background material contains domain information that students need for a proper inquiry experience. The ILS may also contain links to resources outside the ILS itself.
- General tools. E.g., a calculator or a note pad
- Chat or other communication facilities. Means to exchange information with other students.

Go-Lab Portal

The Go-Lab portal is the main landing place for lab-owners, teachers, and students. The Go-Lab portal consists of:

- Labs. A repository of labs
    - Remote Labs
    - Virtual Labs
    - Datasets with their analysis and visualisation tools
- ILSs. A repository of Inquiry Learning Spaces
- Authoring facilities. These enable teachers to create or adapt Inquiry Learning Spaces for their own needs and include:
    - Facilities to adapt and re-sequence the phases of the Go-Lab inquiry cycle
    - Facilities to add or remove guidance (including scaffolds) in the inquiry cycle
    - Facilities to adapt and/or translate guidance (including scaffolds) (with the so-called app composer)
- Additional services:
    - Booking facilities. These enable the booking of remote laboratories
    - Bartering Platform. This platform enables the exchange of services and competencies.
- Go-Lab community. Facilities and support for communication and collaboration on scientific topics and data for teachers and lab-owners.
- Training facilities for teachers. Help facilities for teachers on all components of the Portal (searching, authoring, services, and community).

Scenario

A Go-Lab scenario describes, in a *domain independent way*, all activities, materials, and interactions for teachers and learners that comprise a complete (online and offline) Go-Lab inquiry learning experience. Scenarios differ in activities included and in the combination of a) offline and online activities b) individual or collaborative actions c) distribution of activities over teachers and system, and c) sequencing of activities (see also Weinberger et al., 2011).

Lesson plan

A Lesson plan is a Go-Lab scenario instantiated for a specific domain, specific learning goals, and specific learners. An ILS is part of the lesson plan, but the lesson plan also contains in addition to the ILS information on offline (possibly collaborative) activities. A lesson plan gives structure for all lessons that are planned based on a specific Go-Lab scenario.

Figure 1 shows how scenarios, lesson plans, domains and online labs are related. On one online lab possible more domains can be taught, an example of that is given after the figure. There is one template that describes the elements of all scenarios (see Section 2.2). Different scenarios can be based on this template (see Section 3). One scenario can be instantiated in different lesson plans (including ILSs). This is the case when a different domain is chosen (see

Section 4) but also for the same domain different lesson plans based in the same scenario can be generated depending on the specific choices for resources etc. the designer/teacher will take.

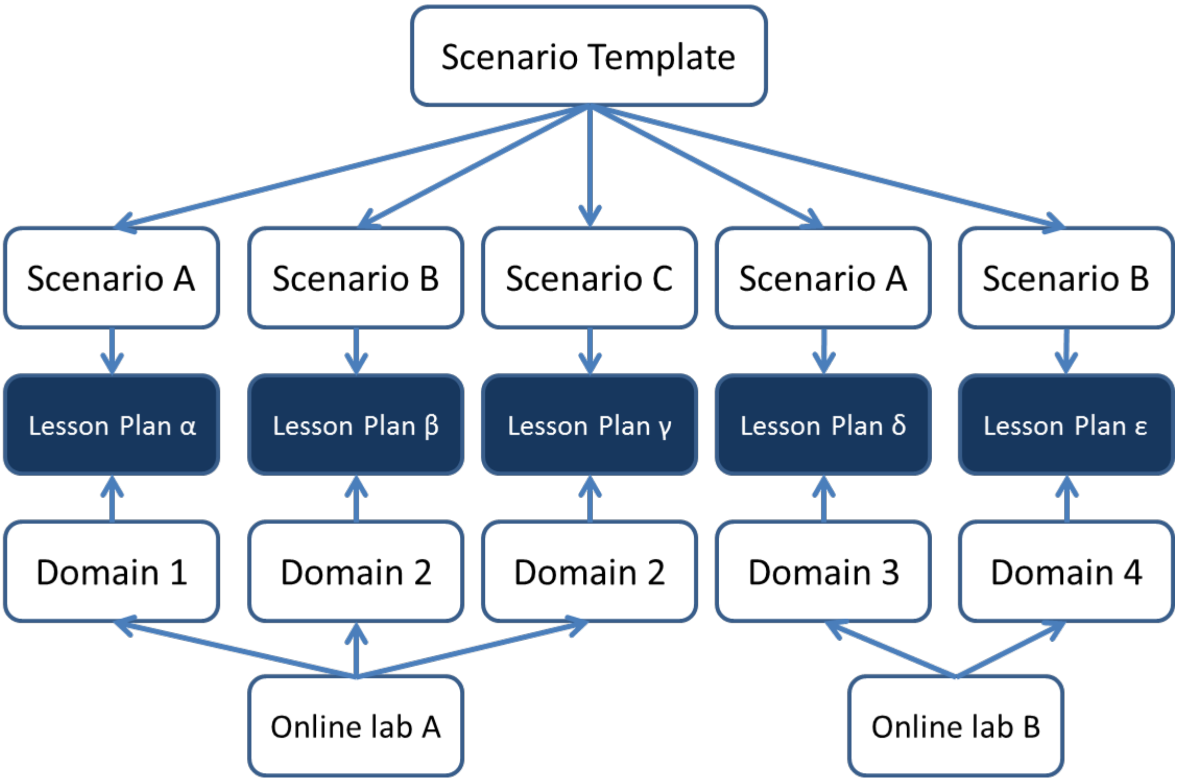


Figure 1. Overview of terminology concerning scenarios, lesson plans, domains, and labs.

An example of how labs and domains go together can be found in the Go-Lab "Splash" online lab. Splash is an example of a virtual lab in which students can learn about different domains. The lab is divided into five tabs with an increasing degree of complexity (Figure 2).The fifth tab with the most complex version elaborates on the simplest version and consists of containers filled with fluid, objects that vary in mass, volume and density, empty measuring cups, scales on which these measuring cups are placed, spring balances, and an area in which students can manipulate objects and define their masses, volumes, and densities, and the density of the fluid.

In the simplest version of the lab, the first tab, students can explore the density domain. Three images of objects filled with dots that represent the density are displayed. Students can change these objects and adjust the mass, volume and density by means of a slider. They can see the object change as they move the slider. If they for instance change the mass of an object, the image of the object will remain the same volume but will be filled with more dots indicating more mass and thus a higher density. The second tab contains a more elaborated version of the lab. As in the first tab students can adjust properties of the objects. However, now these objects are placed in containers filled with water. Students can explore and discover how the density of an object influences if the object floats or sinks in the water. The third tab elaborates on this and adds the possibility to not only adjust object properties but also the density of the fluid in the container, allowing students to find out about relative density. The tabs 2 and 3 illustrate how different parts of a domain can be taught with basically the same lab. The fourth tab adds a measuring cup that is placed on a scale. When an object is dropped in the fluid, the container overflows. The displaced fluid from the container in which the object is dropped flows into the measuring cup, making it possible to measure both the volume and the mass of the displaced fluid. Students can find out that a) if an object sinks, the displaced fluid has the same volume as the object's volume, and b) if an object floats, the mass of the displaced fluid is equal to the mass of the object. Finally, the fifth tab is very much the same as the fourth tab. Students can also adjust the mass, volume and density of the object, and the density of the fluid like in the third and fourth tab, but the measuring instruments are different. Objects are hung on a spring balance that displays the weight of the object. The weight decreases as the object is submerged in the water. At the same time, the container overflows and the displaced fluid flows into the measuring cup that is placed on a scale that shows an increasing weight.

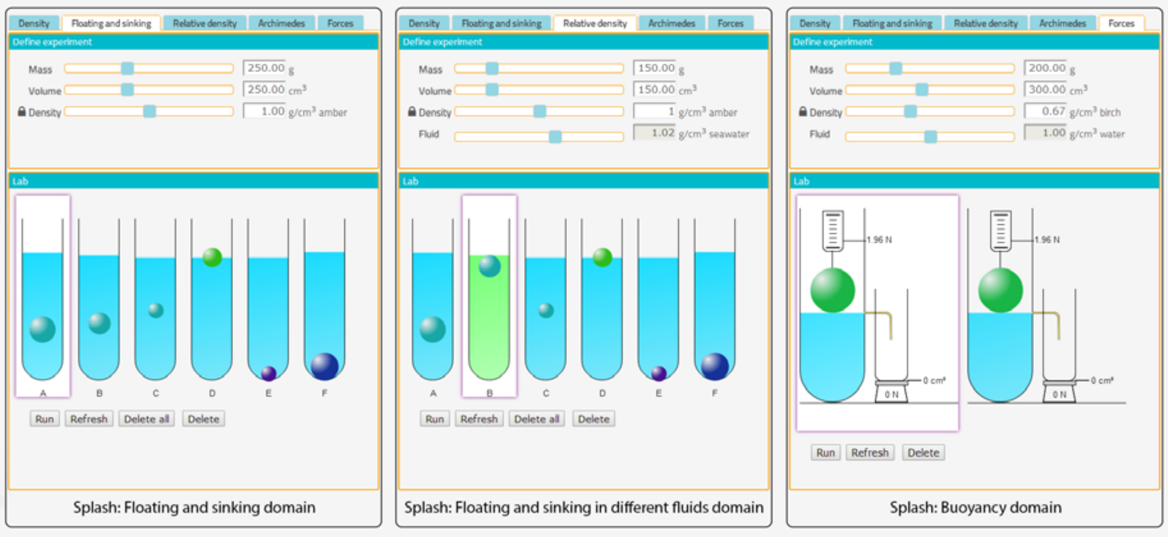


Figure 2. Virtual lab "Splash suitable for different domains topics

2.2 *Scenario template*

Each scenario (and thus also each lesson plan) contains a number of core components. These are:

- Inquiry activities and their sequence.
- A description of activities that are done online and offline
- A description of want should be should be done by students collaboratively (or cooperatively) and individually

2.2.1 Inquiry activities and their sequence

The basic pedagogical scenario as described in deliverable D1.1 describes the core inquiry activities that can be present in a Go-Lab inquiry cycle. The Go-Lab inquiry cycle (see Figure 3) consists of five phases, *Orientation, Conceptualization, Investigation, Conclusion* and *Discussion. Orientation* focuses on stimulating interest towards the domain and curiosity to carry out an inquiry. *Conceptualization* consists of two alternative sub-phases, *Question* and *Hypothesis.* Both sub-phases concern the relations between independent and dependent variables about the phenomenon under study. More specific, "hypothesizing is a formulation of a statement or a set of statements (de Jong, 2006), while questioning is a formulation of investigable questions" (Pedaste et al., submitted). Further, the phase of *Investigation* has three sub-phases; *Exploration*, *Experimentation* and *Data Interpretation*. *Exploration* is a systematic way of carrying out an investigation with the intention to find indications for a relation between the variables involved. *Experimentation* concentrates on selecting variables, the values and the order of the manipulation. *Data Interpretation* focuses on making meaning out of the collected data. *Conclusion* is a phase of reaching basic conclusions of the experiments/investigations. *Discussion* is sharing ones inquiry by *Communication* and *Reflection*. *Communication* is presenting/reporting and sharing the outcomes of your inquiry with others, while *Reflection* is the process of describing, critiquing, evaluating and discussing the whole inquiry process or a specific phase.

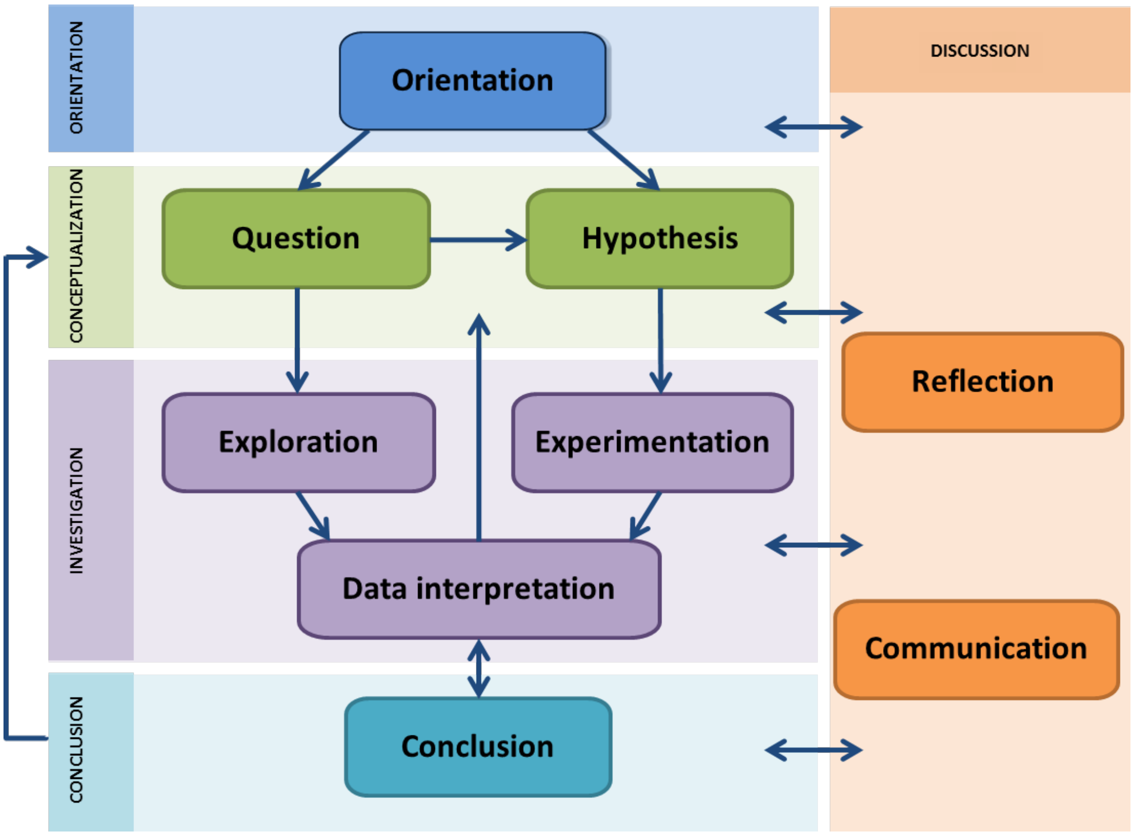


Figure 3. The Go-Lab Inquiry Cycle graphical representation (taken from D1.1).

This basic pedagogical model focuses on gaining inquiry skills when learning in a specific domain. In addition, several metacognitive skills are supported. Students are encouraged to think about research questions, to explore these in a virtual or remote lab when conducting experiments, to draw conclusions based on their results and to reflect upon their processes. This model is suitable for students of 10-18 years old.

The general scenario presented in Figure 1 allows a number of routes/possibilities that could be followed (see Section 3.1). This allows the formation of a number of specific pathways, which after being selected they provide the framework for developing the activity sequence of a lesson plan. For example, one possible pathway is “Orientation – Hypothesis – Experimentation – Data interpretation – Conclusion – Discussion”. This implies that the activity sequence of a lesson plan will follow this specific order of phases. Thus, we will start with Orientation oriented activity/ies, followed by Hypothesis oriented activity/ies, followed by Experimentation oriented activity/ies etc..

2.2.2 On-line vs. Off-line Activities

One of the main purposes of the Go-Lab project is to engage students in inquiry based learning environments through the use of remote and online labs in a way that brings the state of knowledge a step further. In an ILS these activities are performed on-line, this means with the help of a computer (not necessarily using an internet connection). However, this does not imply that the value of experimentation through physical labs is not acknowledged. In contrast, the teachers are free to add off-line activities (which take place outside the Go-Lab environment) to the aforementioned pedagogical scenarios, based on the intellectual needs of their students, the skills that the students have, the affordances that each mode of experimentation offers and the availability of labs (physical, virtual or remote), along with the technical aspects/issues/restrictions that accompany each one of these types of labs. For example, if the learning goal involves having students touch and handle/manipulate concrete material, the teacher should choose the physical lab and include an off-line activity in the activity sequence included in his/her inquiry oriented scenario. If the learning goal involves having students "view" abstract/conceptual objects (e.g., light rays, electron flow), the teacher should choose a virtual lab because it is the only one that could offer such an affordance, and go with the on-line option.

In our perspective, given that all the technical aspects are in place, the most crucial factor for deciding whether to use virtual, remote or physical (virtual and remote relate primarily to on-line activities, whereas the physical relate primarily to off-line) is what affordances each type of lab could offer to the student while experimenting. Recent literature (de Jong, Linn, & Zacharia, 2013) presents a number of the affordances that each type of lab uniquely carries. For example, the physical labs involve all student senses, manipulation of material met in real life and inform students about the safety procedures during the experimentation with physical material/equipment. The remote labs could offer students access to distant equipment (e.g., satellites, telescopes) and equipment rarely or never found in physical school labs (e.g., big size equipment). The virtual labs are the ones with the most affordances, since there were designed to surpass the weaknesses identified with experimenting with physical material. For instance, they could offer a safe and measurement error free environment for experimentation, which surpasses time and space limitations. Moreover, they could offer access to the microscopic and conceptual world of science.

In conclusion, the decision to combine off-line and on-line activities can be seen as a manner of adding value to the learning process and can be done as an alternative based on the needs/limitations of the activity and/or the students. Considering the literature on the unique affordances that each type of lab carries, a combination of off-line and on-line activities, where ever appropriate, will make the scenarios more effective, thus further impacting students' conceptual understanding of science topics and interest towards science.

Switching between on-line and off-line activities can be done in any of the five inquiry phases proposed in Go-Lab (Orientation, Conceptualization, Investigation, Conclusion and Discussion). However, off-line activities must be done whenever this adds value to the learning process without negating the sole purpose of distance and virtual laboratories. For instance, whenever an easy access to a physical laboratory is possible, we suggest that teachers make good use of it during students' investigation. Thus, in the occasion of a simple lesson on electric circuits, it's easy to have a number of wires, batteries and light bulbs available in order to provide the students with the opportunity to manipulate the physical materials and explore how a simple electric circuit can be constructed. However, for the investigation of more complex circuits (multiple batteries/light bulbs in series and/or parallel connection), the use of a virtual lab is preferred since it takes less time to construct, reduces the possibility of making any mistakes, takes more accurate measurements and allows students to compare multiple circuits at the same time. This example can be seen as a combination of physical and virtual labs which can have a substantial impact on conceptual knowledge.

On the other hand, there are some scenarios in which the physical lab experimentation is not possible or require long periods of observation. For example, if the phenomenon under investigation is the phases of the moon or the structure of the universe, then a virtual lab is more appropriate. The use of such a lab allows for faster data collection. Also, in the occasion a laboratory requires the use of dangerous and harmful material, e.g., heavy metals (mercury, etc.), corrosive acids (hydrochloric, sulphuric, etc.), toxic materials (acetone, chlorine, ammonia, etc.), radioactive material (uranium), flammable material (alcohol, gasoline, hydrogen, etc.), remote and virtual labs reduce student danger to the exposure of such materials. Besides the dangers some materials may pose to students, also dangerous can be the processes during the experimental procedure that can lead to violent chemical and explosive reactions. The use of remote and virtual labs can eliminate the danger some experiments may pose and reduce the chance of accidents and/or student injuries.

Taking into consideration the benefits from the combination of off-line and on-line activities, an example from the Electric Circuits lesson plan (see Section 3) is provided in order to make it clear how this can be done using a Go-Lab scenario. In the Orientation phase of the lesson plan, the students participate in an off-line discussion first, facilitated by the teacher, in order to be introduced to the topic of the lesson and start thinking of possible ways to create a simple electric circuit. They receive physical materials (wires, light bulbs and batteries) and work on an assignment with several arrangements of a wire, a light bulb and a battery. First, they have to predict if the light bulb will light up and then, they have to check their predictions through the manipulation of the physical materials. At the end of the assignment, students describe a step by step procedure in order to create a simple electric circuit and discuss with their teacher the weaknesses and problems encountered during the activity. When the off-line activity is completed, students are introduced to the Go-Lab virtual lab environment and familiarize themselves with its functions, tools and symbols on-line. At the end of the Orientation phase, students create a concept map about electric circuits based on the information they gathered, using an on-line concept mapping tool.

In addition to using real laboratories also other activities can be done offline. For example a teacher may decide to have students do reporting off-line or let students work together on an experiment design by having them to write that down on paper. In addition also “tutoring activities” can be done offline by the teacher himself. Typical teacher activities for example concern providing students with demonstrations or doing the scaffolding instead of letting the scaffolding perform by the system.

2.2.3 Collaborative vs. Individual

One of the most important instructional strategies, when using computer technology, concerns the social context of the learning process, namely whether students learn individually (a single student working on a computer) or in a group (two or more students working on a single computer or several computers or offline). Selecting the mode of work (individual vs collaborative) depends on the learning goals set by the teacher and requires from students a number of skills, such as stating explanations and making arguments (Lou, Abrami, & d'Apollonia, 2001). The teacher is responsible for determining the level of these skills and whether the students could collaborate.

Working individually and collaboratively carries its own pros and cons. In the case of the individual mode of learning, the major benefit is that each student could experience a learning process that is better adjusted to his/her individual needs. For example, students could accomplish tasks at their own pace. On the other hand, when using computers individually, you do not offer to the individual the possibility for developing his/her social skills, which are normally part of the regular classroom. In contrast, collaborative group learning has the capability to overcome this possibility of social isolation (R. T. Johnson, Johnson, & Stanne, 1985, 1986). Another major advantage of collaborative learning is that students could learn from their peers (e.g., they could share knowledge and experiences, listen to multiple perspectives/arguments/statements). According to Johnson and Johnson (2004) is better to have students with diverse interests, expertise, perspectives and skills cooperate than work individually because they can fulfil more learning goals than those achieved by an individual. Several theories (e.g., constructivism, socially shared cognition, distributed learning) and empirical investigations support that students learn well when they work together (Lou et al., 2001), including when working with computer supported inquiry learning environments (Zacharia, Xenofontos, & Manoli, 2011).

In Go-Lab collaboration between students will take place off-line, Go-Lab itself, for the moment, doesn't provide students with chat facilities or shared objects.

2.3 Choosing a scenario

For choosing a specific scenario the teacher may let himself guide by a number of consideration. These concern the educational objectives of his lessons, the characteristics of his students, more particular the students' prior knowledge level and the inquiry skills the students possess, and organizational issues.

2.3.1 Educational Objectives

When it comes to teaching science it is valuable to go beyond setting just traditional learning goals that aim to describe the progress with regards to students' cognition and set goals on multiple levels. Every Inquiry Learning Space (ILS) created in Go-Lab can contribute not only in familiarizing students with principles, laws and natural phenomena but also in increasing students' ability to think critically and creatively, to acquire knowledge on how to follow scientific procedures and learn how to make decisions and reflect upon their conclusions.

In Go-Lab, specific educational objectives for online labs have already been presented in Deliverable D2.1:" The Go-Lab Inventory and Integration of Online Labs – Labs Offered by Large Scientific Organisations". The origins of our set of educational objectives goes back to Bloom's Taxonomy of Educational Objectives (Bloom, 1956). This taxonomy had many subsequent revisions and extensions (Anderson & Krathwohl, 2001; Dave, 1975; Fisher, 2005; Harrow, 1972; Krathwohl, Bloom, & Masia, 1973; Simpson, 1972) but the most widely used revised Bloom's taxonomy has been proposed by Anderson, et al. (2001). The set of Go-Lab educational objectives (taxonomy) is based on Bloom's revised taxonomy and was initially proposed within the framework of the OSR project[2].

According to Bloom (1956) educational objectives are usually divided in three categories: cognitive, affective, and psychomotor. Cognitive objectives deal with intellectual results, knowledge, concepts and understanding. Affective objectives include the feelings, interests, attitudes and appreciations that may result from science instruction. The psychomotor domain includes objectives that stress motor development, muscular coordination and physical skills (Trowbridge, Bybee, & Powell, 2000).

Within the framework of the OSR project, a taxonomy of educational objectives had been defined based on Bloom's revised taxonomy, in order to characterize educational scenarios (OSR Project – D2.1). This taxonomy that is also adopted in the Go-Lab Project was initially presented in the Go-Lab deliverable D2.1 and is also is presented in Tables 1, 2, 3, and 4. For each vocabulary term of the taxonomy presented below the existence of a free-text field has been foreseen where the teachers will be able to define how the specific general educational objective is addressed with the use of a specific lab or a specific Inquiry Learning Space.

Table 1. Cognitive Objectives: Types of Knowledge (Anderson & Krathwohl, 2001)

Type of knowledge	Description
Factual	Knowledge of basic elements, e.g., terminology, symbols, specific details,

[2] http://www.osrportal.eu/

	etc.
Conceptual	Knowledge of interrelationships among the basic elements within a larger structure, e.g., classifications, principles, theories, etc.
Procedural	Knowledge on how-to-do, methods, techniques, subject-specific skills and algorithms, etc.
Meta-cognitive	Knowledge and awareness of cognition, e.g.,, of learning strategies, cognitive tasks, one's own strengths, weaknesses and knowledge level, etc.

Table 2. Cognitive Objectives: Processes

Process	Description
To remember	To help the learner recognize or recall information
To understand	To help the learner organize and arrange information mentally
To apply	To help the learner apply information to reach an answer
To think critically and creatively	To help the learner think on causes, predict, make judgments, create new ideas

Note. This classification of cognitive educational objectives should be read as a 'scale': a gradual move towards higher-order thinking (from simple remembering through to transforming information and creating new ideas). Each level builds on and subsumes the previous levels.

Table 3. Affective Objectives

Process	Description
To pay attention	To help the learner focus and pay attention to stimuli, passively
To respond and participate	To help the learner react to stimuli and actively participate in the learning process
To recognize values	To help the learner attach values to stimuli
To form and follow a system of values	To help the learner build a consistent system of values and behave accordingly

Note. This classification of affective educational objectives should be read as a 'scale': a gradual move towards higher-order thinking (from simple reception of stimuli to value-based behaviour). Each level builds on and subsumes the previous levels.

Table 4. Psychomotor Objectives

Process	Description
To imitate and try	To help the learner perform certain actions by following instructions and practicing; reproduce activity from instruction or memory
To perform confidently following instructions	To help the learner refine performance and become more exact, with few errors; execute skill reliably, independent of help
To perform independently, skilfully, and precisely	To help the learner coordinate a series of actions, achieving harmony and internal consistency; adapt and integrate expertise to satisfy a non-standard objective
To adapt and perform creatively	To help the learner achieve high level performance and become natural, without needing to think much about it; automated, unconscious mastery of activity and related skills at strategic level

Note. This classification of psychomotor educational objectives should be read as a 'scale': a gradual move from the simplest behaviour to the most complex behaviour. Each level builds on and subsumes the previous levels.

The same set of educational objectives will also be adopted in the characterization the ILSs. For each objective, the contributor of an ILS will be able to select one of the processes through a drop-down menu while he/she will also have the opportunity to add a description to further specify the objective. Regarding the cognitive domain of knowledge it is possible that an ILS may serve in increasing students' cognition on more than one types of knowledge at the same time. For example, in an ILS that is about Ohm's law, students may learn about the terms and symbols of current, voltage and resistance (factual knowledge) but also how to use the respective mathematical equation in order to make certain calculations (procedural knowledge). The "Cognitive Objective: Types of Knowledge" is what is also referred to as learning goals (subject domain specific goals). Depending on the subject domain of an ILS the contributor will also have the opportunity to specify the learning goal using the free-text field that will be provided next to the respective type of knowledge like in the following example (Table 5) for an ILS based on Ohm's law.

Table 5. An example for setting educational objectives on the Cognitive domain (Types of Knowledge) on a subject specific ILS.

Type of knowledge	Description
Factual	- Learn about the elements of electric current, voltage and resistance.
Procedural	- Learn about Ohm's law mathematical equation and how to solve it in order to calculate the electric current, or the voltage or the resistance within a given electrical circuit. - Learn how to manipulate the elements of an electrical circuit in order to be able.

For each of the remaining three educational objectives namely, Cognitive Objectives: Processes, Affective Objectives and Psychomotor Objectives the contributor of an ILS may choose only one of the processes in order to characterize the ILS, as these classifications should be read as a 'scale': a gradual move from the simplest behaviour to the most complex behaviour. More specifically, each level builds on and subsumes the previous levels as each achievement requires achievement of the prior skill or ability before the next (Forehand, 2005). For example, if an educator believes that an activity in the psychomotor domain achieves in helping students "To perform independently, skilfully, and precisely" this automatically indicates that it also helps them "To perform confidently following instructions" as well as "To imitate and try".

2.3.2 Student characteristics

Student characteristics are important in selecting relevant scenarios and in adapting these. Two main aspects should be considered: (1) students' inquiry skills and (2) prior knowledge about inquiry learning and content knowledge.

2.3.2.1 Inquiry skills

According to D.1.1, the Go-Lab Inquiry Scenario consists of five general inquiry stages: orientation, conceptualization, investigation, conclusion, discussion. To perform each of these successfully students need to possess specific skills which we may call "internal factors".

Funke and Frensch (1995) divided internal factors into *experience, cognitive variables, and non-cognitive variables.* Jonassen (2000) defined 'experience' as familiarity and knowledge, either concerning domain or structure of the task. It enables experts to apply problem schemas which can be employed more automatically while novices have to design this schema and may fail already in that stage (Sweller, 1988). The 'cognitive variables' in the classification of Funke and

Frensch (1995) cover initial knowledge and skills concerning the task and context. Jonassen (2000) pays more attention to the terms of cognitive styles and controls which represent patterns of thinking and reasoning. 'Non-cognitive' factors that influence problem solving are students' self-confidence, perseverance, motivation, and enjoyment (Funke & Frensch, 1995). Jonassen (2000) describes epistemological beliefs in the same context.

In the context of inquiry learning, several skills are needed in particular inquiry stages.

Orientation: observing, searching information.

Conceptualization: identifying a problem, defining a problem, questioning, searching information, brainstorming, hypothesizing, making predictions, analysing needs.

Investigation: planning (methods, tasks, equipment, materials and resources, time), exploring, experimenting, observing, collecting data, analysing data (organizing data, finding patterns, assessing data quality), interpreting data, making inferences, modelling.

Conclusion: finding relationships, drawing conclusions, making inferences, reporting.

Discussion: discussing, presenting and elaborating results, finding arguments and justifying statements, communicating, reflecting, presenting, evaluating the inquiry process and outcomes.

Students either need to have these skills or to receive scaffolds to help them perform them. If a scenario relies heavily on a skills tunes do not possess this may be a reason not to choose that scenario.

2.3.2.2 Prior knowledge

Inquiry is effective if students know what the general goal of inquiry learning is, what stages should be followed in inquiry, what is the aim of each of these stages, how these relate with each other, what is the specific aim of each stage, and how to regulate their learning process (plan, monitor and evaluate). This could be described as general inquiry knowledge (Mäeots & Pedaste, in press). General inquiry knowledge is a set of knowledge about the nature of a coherent inquiry process as a whole, comprehending knowledge about transformative and regulative inquiry processes.

It is not knowledge about how to perform an inquiry activity, e.g., to formulate a hypothesis, but is rather knowledge about the components of the inquiry process as a whole, including knowing the sequence of transformative inquiry stages, the necessity of each stage, and the role of metacognitive processes needed for regulation of inquiry. Therefore, general inquiry knowledge is a crucial element for successful inquiry learning. It leads to the assumption that besides transformative and regulative processes of inquiry there exists the third type of inquiry processes—*inquiry meta-processes*—where the general course of transformative and regulative processes is planned. Inquiry meta-processes can be defined as learning processes that are performed for planning and activating regulative and transformative inquiry processes in a coherent way. The relations between these three types of processes and the knowledge involved in these can be described through a theoretical model of inquiry learning.

Recent research has often concentrated on studying inquiry learning in the context of supporting and developing transformative and regulative inquiry processes and skills (e.g. Gutwill & Allen, 2012; Manlove, Lazonder, & de Jong, 2009; Reid, Zhang, & Chen, 2003; Wu & Hsieh, 2006). Less has been investigated regarding how the students' general inquiry knowledge affects the improvement of other inquiry processes and skills. Thus, considering outcomes of other researchers and results of our previous studies, where the development of transformative and regulative inquiry skills and relations between them were investigated (see Mäeots, Pedaste, & Sarapuu, 2008, 2009, 2011; Pedaste, Mäeots, Leijen, & Sarapuu, 2012), a theoretical model of the inquiry learning was constructed (Figure 4). According to this model, inquiry learning takes place through three inquiry processes: (a) inquiry meta-processes, (b) transformative processes, and (c) regulative processes.

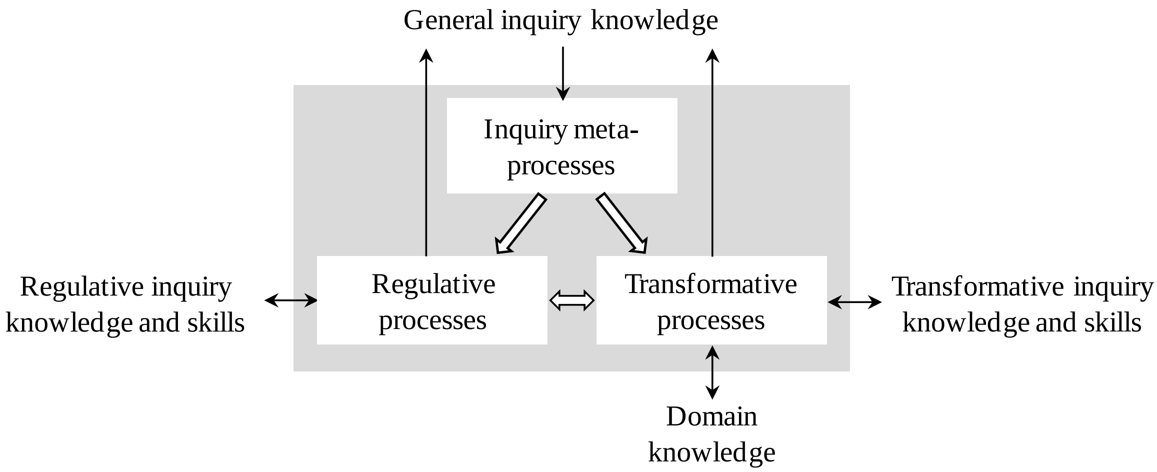


Figure 4. A theoretical model of inquiry learning: (a) processes involved in the inquiry process (grey area), (b) relations between processes (thick arrows), and (c) relations between knowledge and skills related to the inquiry processes (thin arrows). The direction of the arrows indicates information flows between different components of the model

According to this model students' general inquiry knowledge is important for activating inquiry meta-processes that are needed to plan a general course of regulative and transformative processes to achieve their coherence. Meta-processes assume general inquiry knowledge, regulative processes are based on regulative inquiry knowledge and skills, and transformative processes rely on transformative inquiry knowledge and skills. In addition, transformative processes need some input from domain-related knowledge (including procedural knowledge), while the regulative and meta-processes are more general and are based on knowledge that is not domain-dependent, and can be transferred from one context to other without specific limitations.

In conclusion, for successful inquiry the students need the following types of knowledge:

- general inquiry knowledge;
- regulative inquiry knowledge;
- transformative inquiry knowledge;
- domain-related knowledge (including procedural knowledge).

2.3.3 Organizational issues

The choice for a specific scenario is also influenced by the organisational constraints a teacher has in his classroom. Two important constraints are the number of hours a teacher has at his disposal and the possibilities to organise the class.

The didactical hours a teacher has at his disposal may for example determine if a teacher can deploy a full inquiry cycle or only parts of it. For example, a teacher may choose to use only the Investigation phase as a component of a broader activity that he/she has already planned using mostly the school book and some offline activities. Thus the amount of available hours may affect the number of inquiry steps included in an ILS.

Also class organization is a determinant of the scenario to use. Some scenarios will ask teachers to organise their class into subgroups. This means they will need a certain number of students and sometimes students of specific levels of prior knowledge or skills. In the initial available scenarios, the teachers will be provided with respective guidelines on how to organize their class. Judging the composition of knowledge and skills in his class may help the teacher to get a better view on what type of organization to choose (students working as: individuals, in homogeneous groups, or heterogeneous groups). A teacher who wishes to organize the class in small groups will be provided with information on different methods of organization (for example the jigsaw puzzle approach, the six hats approach). Likewise, a teacher who wishes to have the students working individually will be provided with respective guidelines.

2.3.4 Choosing a scenario

Choosing the right scenario (and an associated lesson plan) is an important decision for the teacher. It is a multifaceted decision that cannot be taken following an algorithmic rule. In later versions of the current deliverable we will create more extensive decision support for teachers to select a scenario and/or lesson plan. Currently we one example of how such a decision may take place. This example focuses on a combination of organisational issues (available time and class organisation) and type of desired activity. Later, other examples including different parameters will be included.

Before getting access to an initial scenario the teacher has to set a number of parameters. The answers provided by a teacher on these parameters will define the initial scenario he will be provided with. In order to set these initial parameters the teachers will need to answer a very short three multiple-choice questions (Table 6) set before getting access to a scenario as presented below.

Table 6. Presentation of some parameters that will define the initial scenario provided to a teacher.

Parameter 1: Learning Time Available **How many didactical hours do you have at your disposal?**		
Options	Sub-option	Output
a. 1 didactical hour (Integrated in everyday teaching)	i. Orientation ii. Conceptualization-Question iii. Conceptualization-Hypothesis iv. Investigation-Exploration v. Investigation-Experimentation vi. Investigation-Data interpretation vii. Conclusion viii. Discussion	short one/two steps activity
b. 2 didactical hours (Integrated in everyday teaching)	i. Orientation ii. Conceptualization-Question iii. Conceptualization-Hypothesis iv. Investigation-Exploration v. Investigation-Experimentation vi. Investigation-Data interpretation vii. Conclusion viii. Discussion	short one/two steps activity
c. 3 didactical hours (Integrated in everyday	-	full version inquiry cycle

<table>
<tr><td>teaching)</td><td></td><td></td></tr>
<tr><td>d. More than 3 didactical hours (separate school project, extra-curricular activity)</td><td>-</td><td>full version inquiry cycle</td></tr>
<tr><td colspan="3">Parameter 2: Pathway of Inquiry
Do you plan to make an exploration or an experimentation oriented activity?</td></tr>
<tr><td colspan="2">Options</td><td>Output</td></tr>
<tr><td colspan="2">a. Exploration – orientated activity</td><td>Pathway 1</td></tr>
<tr><td colspan="2">b. Experimentation – oriented activity</td><td>Pathway 2</td></tr>
<tr><td colspan="2">c. Mixed activity (both exploration and experimentation oriented)</td><td>Pathway 3</td></tr>
<tr><td colspan="3">Note: Based on the questions set above, if a teacher selects “a” or “b” in parameter 1, the 2nd parameter can be skipped.</td></tr>
<tr><td colspan="3">Parameter 3 : Class organization
How do you plan to organize your class?</td></tr>
<tr><td colspan="2">Options</td><td>Output</td></tr>
<tr><td colspan="2">a. Class working as a whole</td><td>The Univariable Model (see Figure 7)</td></tr>
<tr><td colspan="2">b. Class working in small groups</td><td>The Multivariable Model (see Figure 8)</td></tr>
<tr><td colspan="2">c. Students working individually</td><td>The Univariable Model (see Figure 7)</td></tr>
</table>

Although at a first glance it may appear that there are numerous different options and numerous different scenarios that need to be created following the parameters set above, this is not the case. An initial scenario basically has two main parts. Depending on the teacher's selections these parameters are combined in different ways, thus allowing the personalization of the initial scenario. The two main parts are:

a) Inquiry steps: Each step of the inquiry cycle is followed by a brief explanatory text which outlines what the teacher is expected to do and write in order to prepare that specific step. Parameters 1 and 2 define which steps of the inquiry cycle will be included in the initial scenario and in what order.

b) Pedagogical Model followed: In any case of an inquiry activity the teacher may choose to follow different strategies in order to organize the lesson and how the students will work. Depending on the class organization the teacher will choose in parameter 3, each inquiry step will be further enriched with additional guidelines that will help the teacher organize the class. These guidelines will stem from pedagogical approaches like the “Jigsaw Puzzle” approach or the “Six hats” approach. Finally, in all cases there will be information available on how to incorporate off-line activities in a lesson plan. Figure 5 presents the different paths and the combinations of components in order to personalize the initial scenario provided to the teachers.

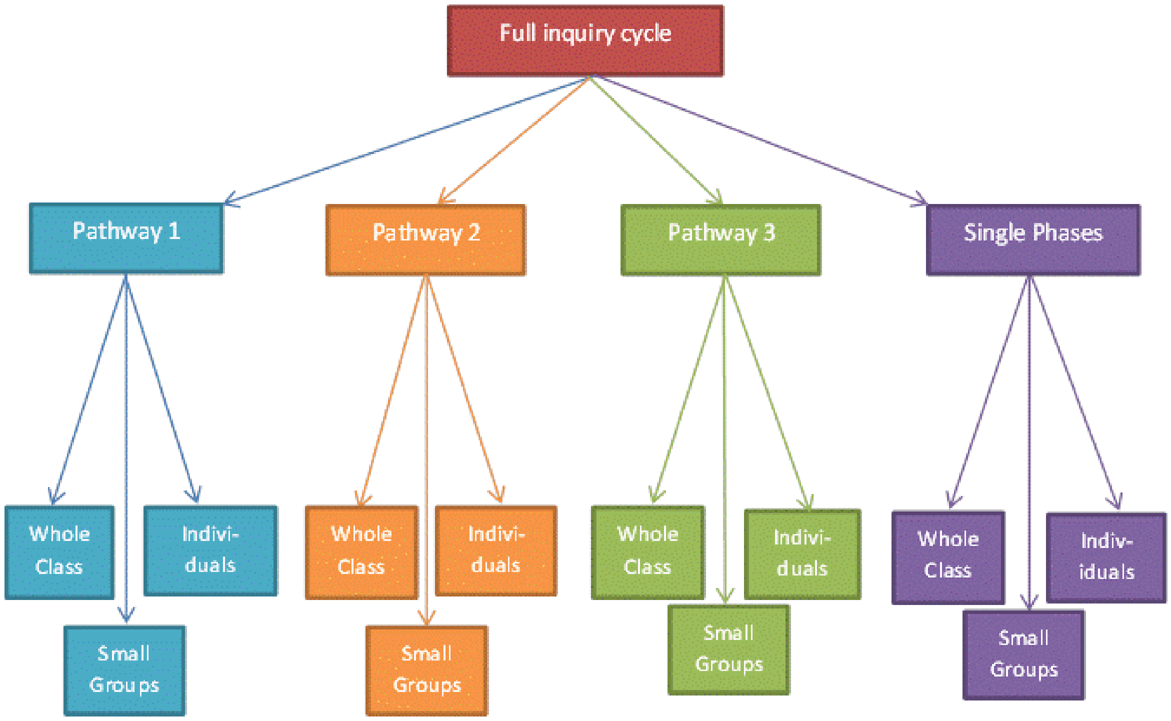


Figure 5. Representation of the different paths and combinations of components in order to personalize the initial scenario provided to the teachers.

3 The Go-Lab scenarios

3.1 The Go-Lab basic scenario; different pathways

In the inquiry cycle graphical representation (Figure 1) there are arrows which display possibilities of sequencing across phases and sub-phases. The actual sequencing will be a teacher's choice, considering students' abilities and needs and the time available. For example, a teacher may choose a completely linear inquiry cycle, thus limiting the number of sub-phase transitions.

There are two main "pathways" through the inquiry cycle (see Figure 6). The first pathway concerns students that have a clear idea which the variables of the phenomenon under study are and what exactly to investigate (hypothesis driven; Test a Hypothesis pedagogical scenario). The second pathway concerns students that start with an open-ended question, without necessarily knowing exactly what the variables under study are (Driving Question pedagogical scenario). The way the experiment is designed may differ between the two occasions (Explore vs. Experiment). More specifically, the two main pathways for each of the two scenarios are:

- Test a Hypothesis pedagogical scenario: Orientation – Hypothesis – Experimentation – Data interpretation – Conclusion – Discussion
- The Driving Question pedagogical scenario: Orientation – Question – Exploration – Data interpretation – Conclusion – Discussion

In any pathway followed, the teachers/students can return from the Conclusion phase to the Conceptualization phase to test more variables or for correcting or enriching the conclusions emerged from previous enactment(s) of the inquiry cycle.

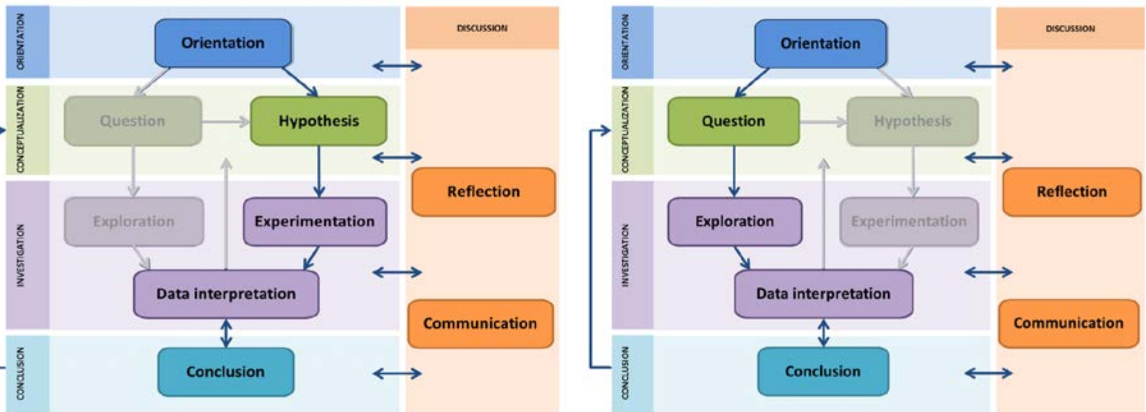


Figure 6. The two basic pedagogical model pathways

While these are the two *basic pedagogical scenario pathways*, other possible pathways are available, which could result from rearranging the inquiry phases and sub-phases. For example:

- Orientation – Question – Hypothesis – Experimentation – Data interpretation – Conclusion – Discussion
- Orientation – Question – Exploration – Data interpretation – Hypothesis – Experimentation – Data interpretation – Conclusion – Discussion
- Orientation – Question – Exploration – Data interpretation – Conclusion – Hypothesis – Experimentation – Data interpretation – Conclusion – Discussion
- Exploration – Orientation – Hypothesis – Experimentation – Data interpretation – Conclusion – Discussion

3.2 The jigsaw approach

The Jigsaw approach is “a specific type of group learning experience where each student must cooperate with his or her peers to achieve his or her individual goals. Just as in a jigsaw puzzle, each student is part essential for the production and full understanding of the final product” (Aronson, 2002, p. 215).

The jigsaw approach could be implemented in a variety of ways, while keeping the aforementioned jigsaw puzzle philosophy constant. Below we describe two different ways, along with their variations for implementing the Jigsaw approach in the Go-Lab basic pedagogical model.

In the first sub-model (see Figure 7), teachers assign each group of students, namely group of experts to test a single variable (V) for a specific range of values (a, b, c, etc.). Each of these groups of students tests a different variable (V1, V2, V3, etc.) and at the end of the investigation, all groups communicate their results for each variable examined separately in order to draw their final conclusions. The number of groups, and students in each group, depends on the size of the class and the number of computers available. The teacher has the final word for the latter.

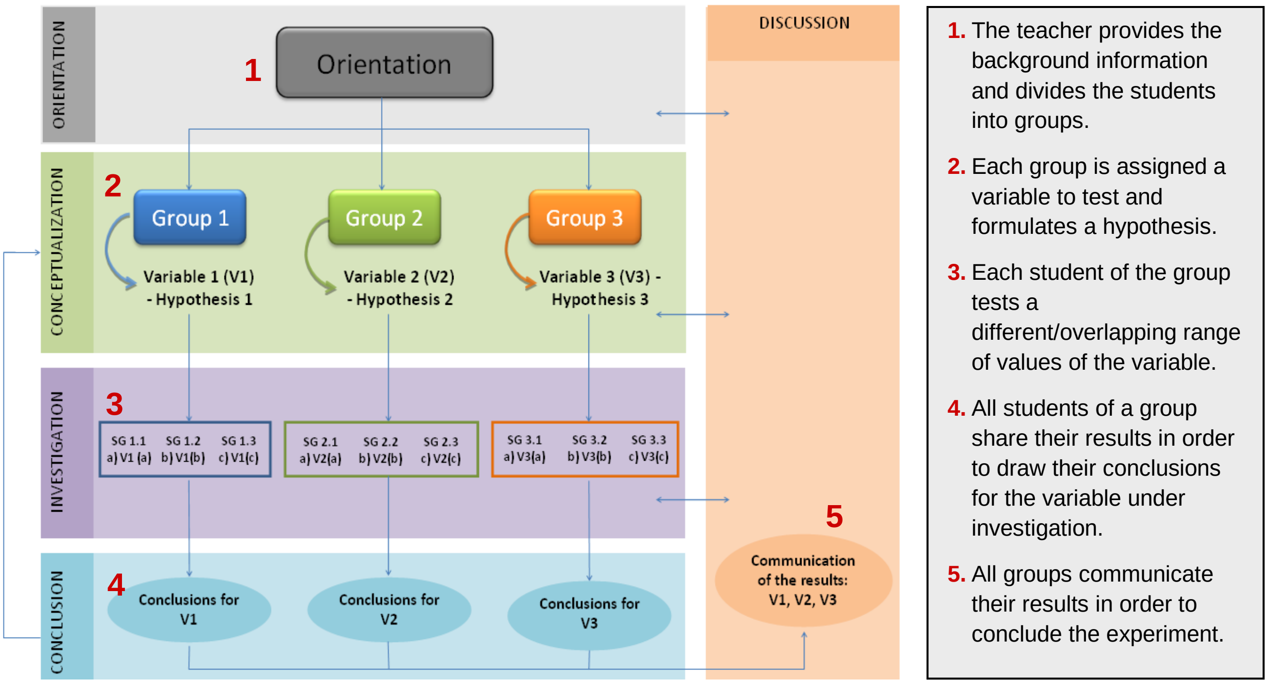


Figure 7. The Univariable Model

The second sub-model still uses the Jigsaw approach, but is implemented in a different way than the first model. While the student/group arrangement resembles that of the first model, the teacher assigns each group all the variables under investigation to test (e.g., V1-V3). At the end of the investigation, all groups communicate their results in order to draw their final conclusions (see Figure 8). The overlap in variables and value ranges could also be used in this case for validation purposes. Similar to the first model, the number of groups, and students in each group, depends on the number of students of the class and available computers on side.

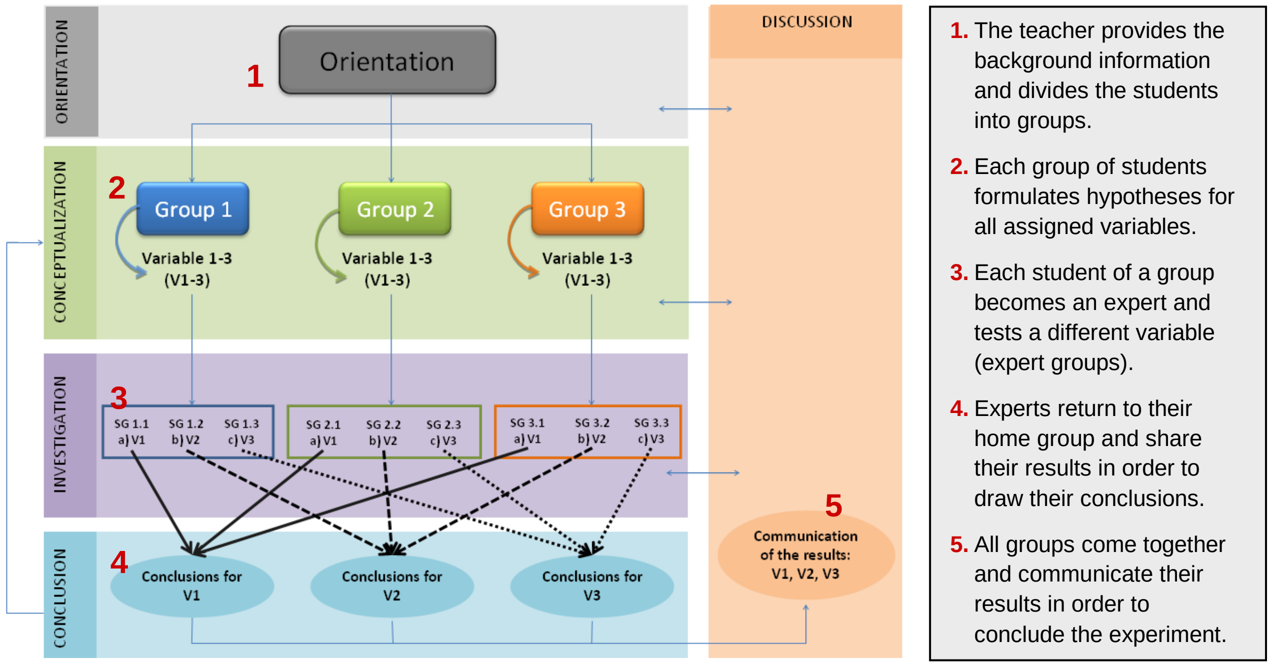


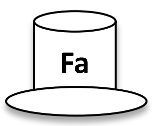
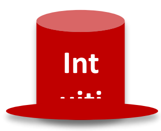
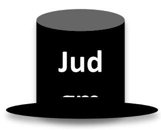
Figure 8. The Multivariable Model

Based on the Go-Lab inquiry cycle (basic pedagogical model), one possible pathway that a student could follow when following the Jigsaw approach is: Orientation – Question – Hypothesis – Experimentation – Data Interpretation – Conclusion – Discussion. However, the teacher should be aware (in order to inform her students) that each one of these phases and sub-phase follows now different practices that derive from the Jigsaw approach (see the grey box in Figure 7 and Figure 8).

3.3 *Changing hats*

Edward de Bono's (2000) *Six Thinking Hats* is a widely adopted creativity technique in various fields such as business management, education, and human-computer interaction. Essentially, *Six Thinking Hats* provides directions for adopting different modes of thinking, characterized by six coloured hats: White, Red, Black, Yellow, Green and Blue (Table 7).

Table 7. Six colour hats, focus of thinking and implication to Go-Lab inquiry learning phases

Thinking hats	Focus	Inquiry Learning Phases Applicable
	Facts, Figures Information	*Orientation, Conclusion, Discussion:* Call for information known and needed, which can be provided by a teacher, peers and other sources. Such information may need to be referenced for supporting discussion as well as conclusion.
	Intuition, Feeling & Emotion	*Discussion*: In reflecting and communicating experiences and insights gained in the learning process, students may express feelings and emotions (e.g., fun, pride, frustration, surprise) to make their points.
	Judgment & Caution	*Conceptualization, Investigation*: Spot the difficulties and risks; find out where and why things may go wrong. In formulating questions and hypotheses, it is critical to think about counterarguments and potential pitfalls.

	Logical Positive	*Conceptualization, Investigation, Conclusion*: Explore the positives and probe for value and benefit. Optimism (but remain alert to biases) sustains engagement in the process.
	Creativity & Alternatives	*Conceptualization*: Identify the possibilities, alternatives and new ideas; an opportunity to express new concepts and new perceptions.
	Overview Process control	*All phases*: It works as a control mechanism to ensure that the guidelines for different modes of thinking are observed. It is essentially a meta-cognitive strategy.

Normally this creativity technique is applied in a group setting. Participants can wear real physical hats or mental ones (i.e., by asking all group members to utter loudly together the colour of the hat or presenting the image of the hat in a way perceivable by all of them). To ensure that participants are aware of the specific thinking mode they are in, thereby thinking with the same focus, it is important that putting on and taking off hats are performed as explicit actions (i.e., gesturing or verbalizing the change of hat). Also, group members should use the same colour hat simultaneously. By switching hats, participants can refocus or redirect their thoughts and interactions (verbal as well as non-verbal). Furthermore, the hats can be used in any order that is deemed appropriate and can be repeated as many times as necessary to address the issue at hand.

In fact, the Six Thinking Hats technique has been applied to teach STEM subjects (Childs, 2012; Garner & Lock, 2010) with several advantages being identified. In summary, it can:

- reflect the process of experimentation within STEM subjects;
- help simplify and hence provide focus on one process at a time;
- enable a collaborative group learning activity;
- provide a common language within a group, while removing ego and reducing confrontation;
- promote creativity and problem solving;
- stimulate diversity of thought and empathy;
- foster evaluation skills leading back to improving processes and testing new hypothesis;

Implementing *Six Thinking Hats* in the Go-Lab basic pedagogical model is relatively straightforward, as illustrated and described in Figure 9. Note that the teacher is required to orchestrate the process of switching hats, because it is a collaborative activity. However, if the class size is big, synchronizing the process may be somewhat difficult. Alternatively, the class can be split into smaller groups. For each group, a group leader is identified; he or she is responsible to coordinate the timing for changing hats and to ensure that members are applying the same focus (Table 7) to think about the issue under scrutiny.

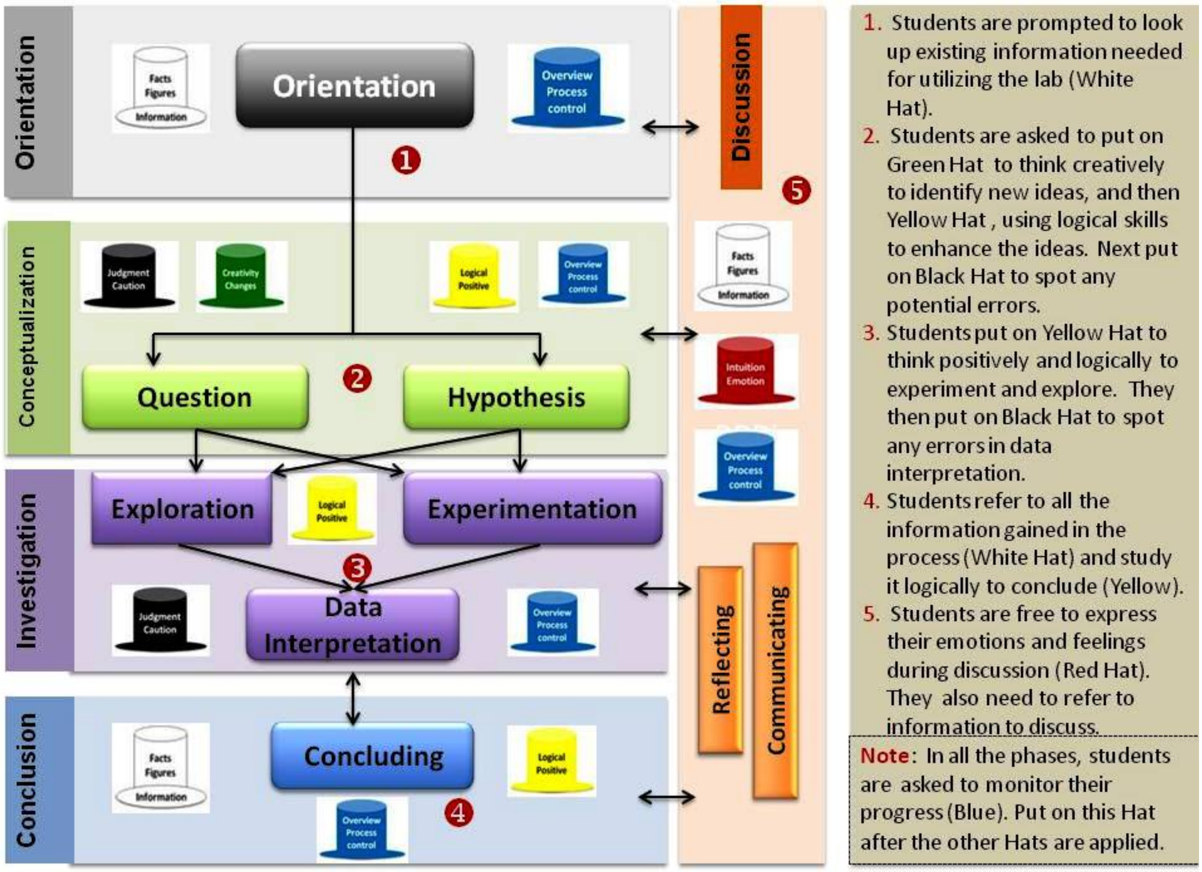


Figure 9. ***Example of applying different colour Thinking Hats to the inquiry learning phases***

While Figure 9 exemplifies which colour Hats are applicable for which inquiry learning phases, there is much leeway for a teacher (or a student group leader) to adapt the use of Hats based on the abilities as well as preferences of group members, the group dynamics, and certain situational factors.

3.4 Learning by critiquing

Learning by critiquing aimed at the development of critical, scientific thinking, aimed at (senior) secondary school students. Students learn to judge the accuracy and reliability of research and to design a 'fair' inquiry, measure accurately, determine whether measurements are reliable and lead to valid conclusions Students gain knowledge through peer discussion and get an idea about what it means to be part of a simulated research community. An example of this scenario can be found in work in chemistry (van Rens, 2013a, 2013b).

Figure 10 gives a graphical view of the steps students take in this scenario. A teacher starts by critical selecting an article relevant to the chosen domain. This article contains some flaws concerning its methods or some measurement errors. Students start by reading this article and answering some basic questions about the independent and dependent variables under investigation. Next students answer questions about the experimental set-up and the performed measurements. Students write a critical review on the article guided by these questions. The results are discussed during a classroom discussion.

In the next phase students will perform an investigation themselves. Students are divided into groups and each group investigates their own research questions and hypotheses. They describe their research questions and hypotheses, experimental set-up, measurements and conclusion in a report, preferably in the form of a scientific article. Next students will again perform a critiquing exercise by reviewing the article of another group. This process is guided by questions like the ones in Table 8.

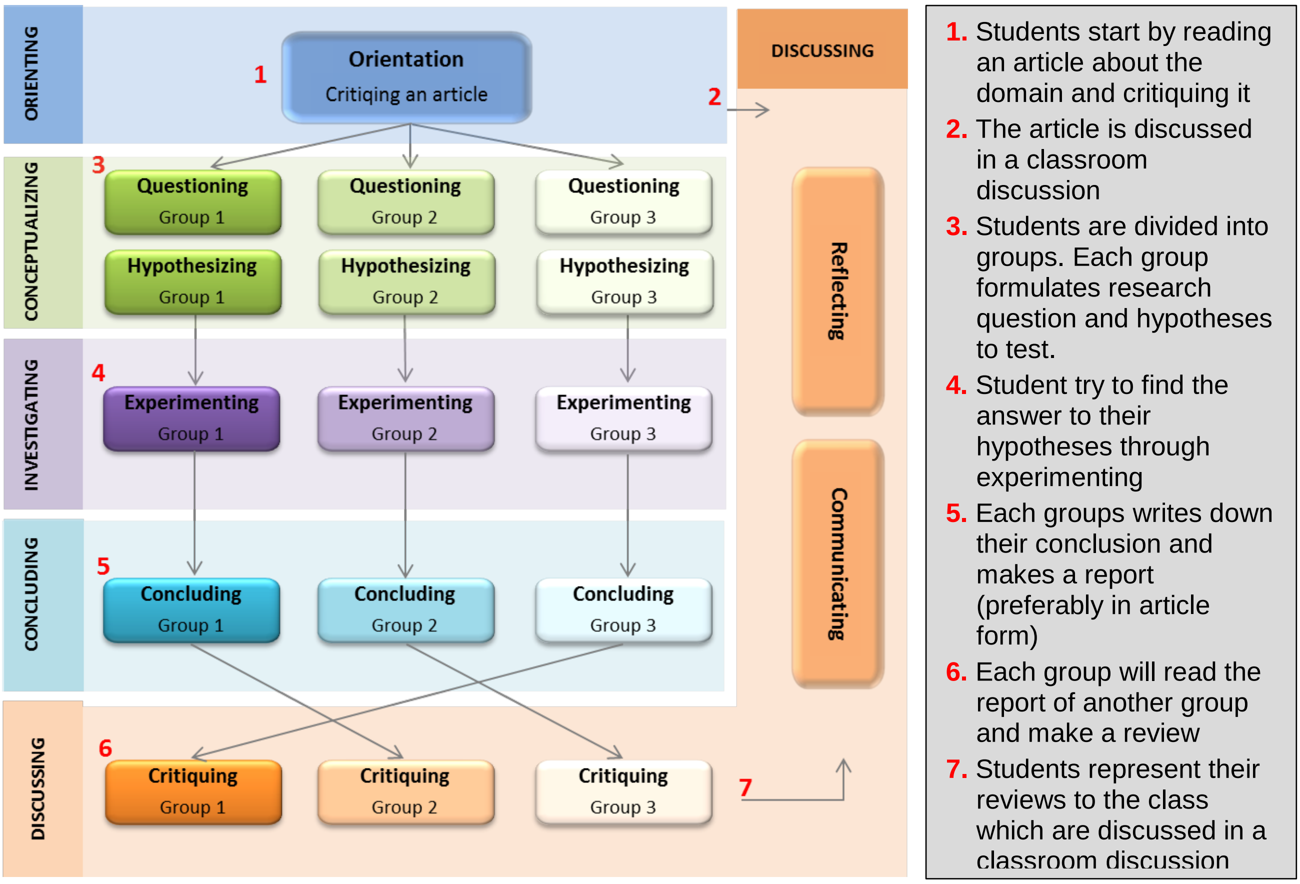


Figure 10. Process of students through the phases of the inquiry cycle

Table 8. Question guiding the review

Questions guiding the review of students reports
Are the assumptions and theory about the hypothesis correct?
Are all relevant control variables considered?
Are the observations accurate?
Are the results well presented?
Did the author make the right calculations?
Are the discussion and conclusions valid?

Students will briefly present their review to the class and the authors of the report get a chance to respond. The teacher ends the lesson by reflecting on the activities and summarizing what students have learned. The emphasis of this scenario is on discovering possible threats to the validity and reliability of a scientific experiment.

4 Lesson plan examples

In this section a number of example lesson plans are presented. In this section only the metadata of the lesson plans are presented (the "about" section). The full lesson plans can be found in Annex A.

4.1 Electric circuit – In series and in parallel set-up

ABOUT THE LESSON PLAN

Go-Lab metadata:

ILS Title: In series and in parallel set-up

ILS Description: The basic idea of the lesson plan is to familiarize the students with the elements that compose a simple electric circuit (as well as electric circuits in general) and enable them to formulate an operational definition. The students will be introduced to both parallel and in series circuit set-ups.

Subject Domain: Electricity, direct current, simple electric circuit, in series circuit, in parallel circuit

Keywords: simple electric circuit, in series set-up, in parallel set-up, brightness, electric current, flow

Language: English

Grade Level: Upper secondary education (15-16 years of age)

Average time of use: 2 didactic hours (2 x 45 minutes)

Educational Objectives (Types of knowledge):

Factual: Learn about the differences between in series and in parallel circuits.

Conceptual: Formulate operational definitions of the simple electric circuit, in series and in parallel set-up.

Procedural: Construct a simple electric circuit with real material and design electric circuits using symbols.

Meta-cognitive: Reflect on the activities done and the results of the exploration.

Use of guidance tools and scaffolds: Notepad, calculator, twitter app, check spelling, concept mapping scaffold, questioning scratchpad

Additional metadata:

Scenario: Variation of basic scenario, Orientation – Question – Exploration – Data Interpretation – Conclusion – Reflection

Students' prior knowledge and skills:

- No domain knowledge is required since this is the first lesson on the unit of electricity.
- Basis ICT skills
- Basic inquiry and reflective skills in order to address the requirements of the activity

Organizational requirements:

- Computer lab (minimum 6 computers, one for each group)

Online Lab:

- Electricity Lab[2] (virtual lab)

[2] Electricity Lab was developed by Jakob Sikken (University of Twente)

4.2 Electric circuit – Ohm's law

ABOUT THE LESSON PLAN

<u>Go-Lab metadata:</u>

ILS Title: Ohm's law

Brief Description: The basic idea of the lesson plan is to familiarise the students with the elements that compose a simple electric circuit (as well as electric circuits in general) and enable them to formulate an operational definition. Moreover, this lesson plan aims at guiding students to conduct scientific investigations in order to identify the concepts/variables involved in the domain of electric circuits. These concepts are: Current (I), Voltage (V) and Resistance (R). Given these concepts, students will be guided to understand the relationships between these concepts which lead to Ohm's law.

Subject Domain: Electricity, direct current, in series circuit, in parallel circuit, Ohm's law

Keywords: current, resistance, voltage, ammeter**,** ohmmeter, voltmeter, electric circuits

Language: English

Grade Level: Upper secondary education (15-16 years of age)

Average time of use: 2 didactic hours (2 x 45 minutes)

Educational Objectives (Types of knowledge):

<u>Factual:</u> Learn about Ohm's law.

<u>Conceptual</u>: Know the relationship between the electric current, voltage and resistance, and define the Ohm's law.

<u>Procedural</u>: Create a graphical representation of current and voltage and a graphical representation of current and resistance.

<u>Meta-cognitive:</u> Reflect on the activities done and the results of the investigations.

Use of guidance tools and scaffolds: Notepad, calculator, twitter app, check spelling, hypothesis scratchpad, experiment design tool

<u>Additional metadata:</u>

Scenario: Jigsaw approach

Students' prior knowledge and skills:

- No domain knowledge is required since this is the first lesson on the unit of electricity.
- Basis ICT skills
- Basic inquiry and reflective skills in order to address the requirements of the activity

Organizational requirements:

- computer lab (minimum 6 computers, one for each group)

Online Lab:

- <u>Electricity Lab</u> (virtual lab)

4.3 Conservation of momentum

ABOUT THE LESSON PLAN

Go-Lab metadata:

ILS Title: Conservation of momentum

ILS Description: Students will determine the total momentum from all particles tracked after a particle collision and they will calculate the missing momentum (magnitude & direction).

Subject Domain: : Accelerators & beams, Calorimeters, Particle beam parameters, Particle detectors, Angular velocity, Collision, Conservation of momentum

Keywords: mass, velocity, acceleration, energy, momentum, collision, conservation of momentum, radians, degrees, vector

Language: English

Grade Level: Upper Secondary Education (15 -18 years old)

Average time of use: 3 didactic hours (2 x 45 minutes)

Educational Objectives (Types of knowledge):

Factual: Learn about the conservation of momentum.

Conceptual: Get acquainted with particle physics research

Procedural: Learn how to add vectors, Measure vector angles and convert radians to degrees of angle

Meta-cognitive: Learn how to process real scientific data from the ATLAS experiment

Use of guidance tools and scaffolds: scratchpad, calculator, hypothesis scratchpad, concept map

Additional metadata:

Scenario: Variation of basic scenario, Orientation – Hypothesis – Experimentation– Data Interpretation – Conclusion – Reflection

Students' prior knowledge and skills:

- Background knowledge in Newton's Law's, momentum, mathematical vectors
- Basis ICT skills
- Basic inquiry and reflective skills in order to address the requirements of the activity

Organizational requirements:

- Computer lab (minimum 6 computers, one for each group)

Online Lab:

- HYPATIA (Data Set/Analysis Tool)[3]

4.4 Buoyancy

ABOUT THE LESSON PLAN

Go-Lab metadata:

ILS Title: Buoyancy, Archimedes principle

ILS Description: Students work in groups and design and perform their own experiment about Archimedes' principle. The thinking hats are used to help guide the decisions the groups makes

[3] HYPATIA was developed by a team of authors, see Barnett et al. (2012).

when creating and selecting research questions and hypothesis, designing experiments and drawing conclusion.

Subject Domain: Buoyancy, density, Archimedes principle

Keywords: Archimedes principle, buoyancy, density

Language: English

Grade level: Upper Secondary Education (14 – 18 years old)

Average time of use: 2 didactic hours

Educational Objectives (Types of knowledge):

Factual: Learn about mass, volume, density and fluid displacement

Conceptual: Learn how Archimedes principle influences situations

Procedural: Learn how to perform an experiment

Meta-cognitive: Learn how to approach situations from different perspective, practice parallel thinking

Additional metadata:

Scenario: Thinking hats

Students' prior knowledge and skills:

- Students need to be familiar with the concepts of mass, volume and density. They should have some experience with experimentation and some basic knowledge about what research questions and hypotheses are and how to draw conclusions

Organizational requirements:

- Students will work in groups of 3 or 4. The lesson will end with a discussion with the entire class.
- At least one computer per group of 3 or 4 students.

Online Lab:

- Splash[4] (virtual lab)

4.5 Galaxy Classification and Formation

ABOUT THE LESSON PLAN

Go-Lab metadata:

ILS Title: Galaxy Classification and Formation

ILS Description: The following exercise aims to introduce to students the concept of varying galactic morphologies. Students will look in detail at images of numerous galaxies and they will attempt to classify them according to the Hubble Classification Scheme. Moreover, the class will try to investigate the origin of the shapes of the galaxies that stem from galaxy interactions.

Subject Domain: Elliptical galaxy, Formation, Galaxies and Dwarf galaxies, Spiral galaxy, Irregular galaxy, Gravitational field, Collision, Gravitational force and gravity, Velocity, Universal law of gravitation

Keywords: galaxies, spiral, elliptical, irregular, gravity, formation, interaction, tuning fork, classification

Language: English

[4] Splash was developed by Anjo Anjewierden (University of Twente).

Grade Level: Primary Education (10 -12 years old)

Lower Secondary Education (12 -15 years old)

Upper Secondary Education (15 -18 years old)

Average time of use: 3 didactic hours (2 x 45 minutes)

Educational Objectives (Types of knowledge):

Factual: Learn about the different shapes of galaxies and about the Hubble classification system.

Conceptual: Learn about the concept of gravity, how galaxies interact and how they are formed.

Procedural: Learn about simulations and how they may be used in a scientific context.

Meta-cognitive: Get acquainted with making and studying astronomical observations.

Use of guidance tools and scaffolds: scratchpad, calculator, hypothesis scratchpad, concept map

Additional metadata:

Scenario: Variation of basic scenario, Orientation – Hypothesis – Experimentation– Data Interpretation – Conclusion – Reflection

Students' prior knowledge and skills:

- No domain knowledge is required since this is the lesson.
- Basis ICT skills
- Basic inquiry and reflective skills in order to address the requirements of the activity

Organizational requirements:

- Computer lab (minimum 6 computers, one for each group)

Online Lab:

- Faulkes Telescopes[5] (Remote Lab), Galaxy crash[6] (Virtual Lab) [reference needed]

[5] © Faulkes Telescope Project, official partner of Las Cumbres Observatory Global Telescope Network

[6] Scientific Development: Chris Mihos (CWRU), Greg Bothun (UOregon)
Java Programmers: Chris Mihos, Dave Caley (UOregon), Bob Vawter (CWRU)
Web Design: Cameron McBride (CWRU)

5 The default ILS

The purpose of having a default ILS is to provide default texts so that teachers can quickly get started when preparing their own ILSs. The default text shows how information can be organized within an ILS and offers a convenient way to introduce ILS inquiry phases and guidance to students. All texts can of course be easily modified by the teachers.

In the default ILS there is a beginning section that serves as a place to briefly describe what the ILS is about. This “Description” section remains visible to a learner throughout the learning process.

Below the “Description” section is where the main content of the ILS is found. It consists of the five general phases of the inquiry cycle: Orientation, Conceptualization, Investigation, Conclusion, and Discussion. The inquiry phases are viewed in a tabbed browsing interface making it easier to navigate among them. In the default ILS, each phase has default text that introduces the purpose and actions associated for that particular phase.

Inquiry is a complex learning approach and it is important to provide general guidelines to learners during their inquiry process. In the following, general guidelines for introducing inquiry phases are described and then the default text for each ILS inquiry phase is presented.

In this deliverable we focus on default texts that introduce an inquiry learning phase. In next versions of this deliverable we will also include default texts for other types of guidance (e.g., heuristics).

5.1 Orientation

Orientation is a phase focused on stimulating students’ interest and curiosity towards a topic. The Orientation phase should also familiarize students with the learning topic and prepare them for inquiry learning. Preparing students for the Orientation phase can include activities such as

- introducing a problem with engaging multimedia material;
- providing sufficient prior content knowledge;
- having students practice taking and organizing notes;

The default text in the Orientation phase reads as:

> *Dear student,*
>
> *In today’s lesson you will learn to understand* “insert learning topic”*. You will go through an inquiry cycle making “*insert list of relevant inquiry related activities*” just like an authentic scientist might do in real-world laboratory conditions. Moreover, you will have the opportunity to work with the* “insert name of online lab” *online science laboratory to perform personalized experiments.*

A typical scaffold used in the orientation phase is the concept mapping tool.

5.2 Conceptualization

In the Conceptualization phase students focus on stating theory-based questions or hypotheses. In fact, Conceptualization is divided into two sub-phases (Question and Hypothesis) depending on whether the focus of the inquiry is best represented by formulating a research question or formulating a hypothesis. Activities to guide students in the Conceptualization phase include:

- explaining what a research question or hypothesis is;
- having students practice formulating meaningful and scientifically oriented questions;

- having students practice hypothesis generation by emphasizing links to a theoretical model;
- explaining the role of research questions and hypotheses in inquiry and why they are important.

The default text in the Conceptualization phase, when the Question sub-phase path is followed, reads as:

> *Now you are in the Conceptualization phase. In this phase you will formulate one or more research questions. Please use the "*insert name of scaffold*" to formulate your research question(s).*

The default text in the Conceptualization phase, when the Hypothesis sub-phase path is followed, reads as:

> *Now you are in the Conceptualization phase. In this phase you will formulate one or more hypotheses. Please use the "*insert name of scaffold*" to formulate your hypotheses.*

A typical scaffold that can be used in the Conceptualization phase is the hypothesis or questioning scratchpad (van Joolingen & de Jong, 1991).

5.3 Investigation

Investigation is a process of planning exploration or experimentation, collecting and analysing data based on the experimental design or exploration, and interpreting outcomes. There are three sub-phases in the Investigation phase: Exploration, Experimentation, and Data Interpretation. Activities to guide students in the Investigation phase include

- making sure students understand the connection between the investigation phase and the research questions or hypotheses they formulated;
- providing students' with information about systematic experimental procedures (e.g., changing only one variable at a time);
- introducing the online laboratory selected for your investigation;
- having students practice drawing and interpreting tables and graphs.

The default text in the Investigation phase, when the Exploration sub-phase path is followed, reads as:

> *Now you are in the Investigation phase. You have stated your research questions about "*insert learning topic*" and will now begin to explore those questions more deeply using the "*insert name of online lab*" online science laboratory.*

The default text in the Investigation phase, when the Experimentation sub-phase path is followed, reads as

> *Now you are in the Investigation phase. You have stated your hypotheses about "*insert learning topic*" and will now begin to testing those hypotheses more deeply using the "*insert name of online lab*" online science laboratory.*

The default text for the Data Interpretation sub-phase reads as:

> Now you will use the data you collected to make further investigations, Please use "insert name of scaffold" to organizes your data so that you can begin to process your results.

Scaffolds that are relevant for this phase are the experiment design tool and the data viewer.

5.4 Conclusion

The Conclusion phase is a process of making conclusions based on the data that has been collected and processed during the Investigation phase. During this phase students can decide whether their original research questions or hypotheses are answered or supported by the outcomes of their investigation. Activities to guide students in the Conclusion phase include

- drawing student attention back to their original research question(s) or hypotheses
- explaining the necessity of making conclusions based on the results of the data;

The default text in the Conclusion phase reads as:

> *Now you are in the Conclusion phase. You have made investigations using "*insert name of online lab*" online science laboratory and enhanced your knowledge about "*insert learning topic*". Based on the data you collected, you are now in a position to state your final conclusions. Please use the "*insert name of scaffold*" to document your conclusions. Remember to compare your data results with your initial "*insert research question(s) or hypotheses*".*

A scaffold suitable for documenting conclusions is the Scratchpad app. A more dedicated scaffold for this phase is being developed.

5.5 Discussion

The Discussion phase is a process of sharing ones' findings through communication with others and controlling the entire learning process through reflecting activities. There are two sub-phases in the Discussion phase: Communication and Reflection. Activities to guide students in the Discussion phase include

- explaining the importance of communication and reflection in scientific inquiry;
- having students write down their reflections of different inquiry phases;
- encouraging students to present their findings in creative ways to their classmates.

The default text in the Communication sub-phase reads as:

> *Now you should communicate on the progress and the status of your inquiry. Please share your results by "*insert sharing method*".*

Possible sharing methods for Communication can include sharing results between individual students or a presentation to the entire class.

The default text in the Reflection sub-phase reads as:

> *Now you should reflect on the progress and the status of your inquiry. Please share your reflection by "*insert sharing method*".*

The sharing methods for Reflection can include writing down what has been learnt up to that point in the inquiry process and commenting on the process. For a final reflection on the inquiry process, students should reflect on the whole learning process and consider the following questions: (1) Did the formulated conclusions answer the research question or hypothesis? (2) What should be done differently next time when performing an inquiry? (3) What should be done similarly next time when performing an inquiry?

Also for the discussion phase dedicated scaffolds will be developed in Go-Lab.

6 How teachers learn about scenarios and lesson plans

When a teacher enters the Go-lab portal he can either search for a specific lab or an Inquiry Learning Space. He may find these at www.golabz.eu (see Figure 11). If he selects a lab he will be informed about available ILSs and lesson plans for this lab. The metadata of these ILSs and lesson plans will indicate which scenario they are based on. If there is no ILS available for a lab the teacher will find the option to create his own ILS or lesson plan (see Figure 12). A teacher can choose to use a scenario to base his ILS or lesson plan on. This process will be explained below.

Figure 11. Screenshot of the Go-Lab Portal: search for a lab or an ILS

When there is an ILS available but no (suitable) lesson plan, the teacher selects an ILS and then may choose the option 'create a lesson plan'. This lesson plan will be based on the scenario that is used in the chosen ILS.

A teacher can also choose to search an ILS instead of a lab. (When searching for an ILS, a teacher can specify his search, indicating that he only wants to search ILSs based on a specific scenario). When he chooses an ILS he can either choose to use an existing lesson plan, adapt an existing lesson plan, or create his own.

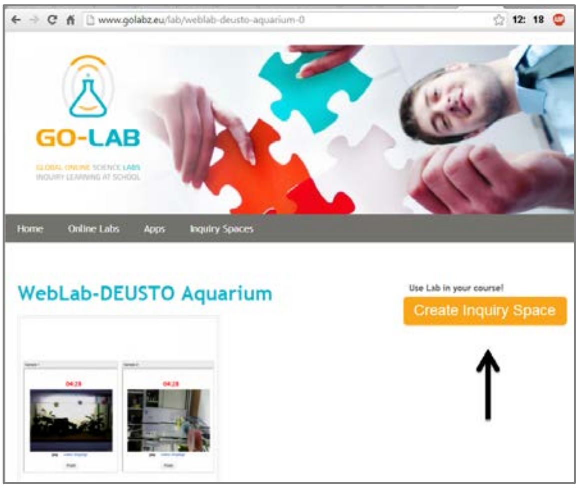


Figure 12. Screenshot of the Go-Lab portal: the option to create an ILS for a specific lab

As explained in Chapter 1, an ILS and a lesson plan are highly related. A lesson plan contains basically the same information as an ILS but with additional information about off-line (collaborative) activities and notes for the teacher. Materials like videos, tools (scaffolds) and labs which are part of an ILS are mentioned in the lesson plan, but not actually part of it. Because of this close relation between ILSs and lesson plans it makes sense to give teachers the opportunity to create and/or consult them at the same time.

6.1 Consulting a lesson plan

The lesson plans examples described in this deliverable (Annex A) are on paper. Although teachers will have the opportunity to use such paper based lesson plans, the idea is that in Go-Lab the primary way offering lesson plans (and scenarios) will be online. A lesson plan can then be viewed and authored in the teacher view of Go-lab. In this view an ILS and a lesson plan can be presented in the same screen (see Figure 13).

Figure 13 shows part of the buoyancy lesson plan described in Section 4.4 and Annex A with its corresponding ILS. The orange bar in the top of the screen indicates that this is the conceptualisation phase. On the left side of the screen the ILS is depicted. A teacher can adapt the ILS by changing the text and adding tools (scaffolds), videos, or pictures. When a teacher is satisfied, he can save the ILS and press the share button to create a link to the student view of the ILS.

On the right side of the screen the lesson plan is displayed. In the paper based version of the lesson plan you can find all the text and assignments which are also in the ILS. Because online we can present both the ILS and the lesson plan in the same screen, it is not necessary to repeat information from the ILS in the online lesson plan. As can be seen in Figure 13 the lesson plan thus only contains information which can't be found in the ILS: teacher notes, off line activities, classroom organisation and (off line) materials.

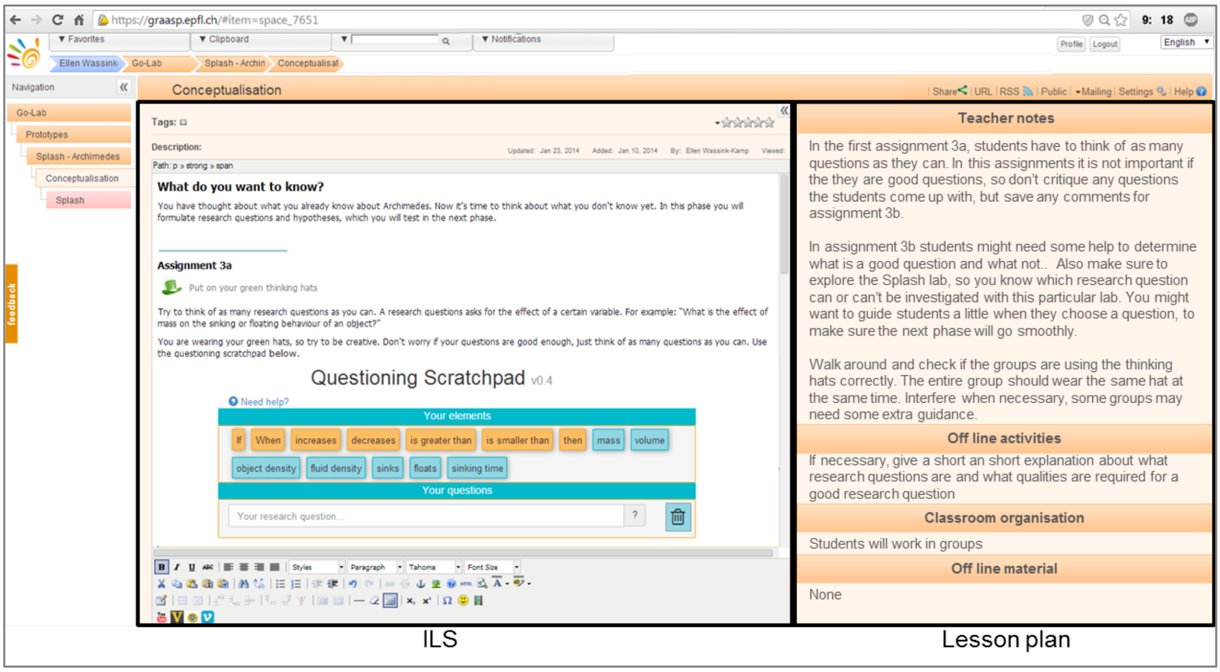


Figure 13. Integrated ILS and lesson plan

The lesson plans are created and presented per phase, just like an ILS. To get an overview of the entire lesson, teachers can print the plan. This will create a lesson plan as presented in this deliverable, were the ILS and the lesson plan are combined.

6.2 How teachers will create or adapt a lesson plan

Teacher can create their own lesson plans for existing ILSs or adapt a lesson plan which is written for a specific ILS. Most ILSs will be based on specific scenario. This scenario will impact the lesson plan. For example if an ILS is based on the jigsaw scenario, students will be assigned to groups in certain phases. So in the 'teacher notes' section of the lesson plan, it should be described that a teacher should assign students to groups, the number of students that should be in each group and how a teacher should deal with individual differences within the groups etc. In the section ‘classroom organisation’ it should be described, per phase, whether students will work alone, in groups or with the entire classroom. This information will be the same for every lesson plan using the jigsaw scenario, independent of the domain or lab that is used. This means that part of the lesson plan can be filled automatically according to the chosen scenario.

If a teacher chooses to create a lesson plan for an ILS based on the jigsaw approach and he clicks on ‘creating a lesson plan’ he will get a lesson plan which is partly filled with default text. This default text is based on the scenario in the ILS. If necessary, a teacher can adapt this text to fit his own needs.

If a teacher decides not to use a readymade ILS, he can create his own. If he clicks on ‘create Inquiry Space’ he will open the default ILS (see Chapter 5). This template contains information about what kind of information is expected in every phase. When a teacher chooses to use a scenario different from the basic scenario, the template will also contain specific information about the chosen scenario. A teacher can choose to create his lesson plan simultaneously with creating his ILS, but can also create or adapt the lesson plan afterwards. This gives him the opportunity to incorporate his experience in the classroom.

6.3 How teachers will collaborate online and share lesson plans

Teachers can share the lesson plans they have created (starting from interface given in Figure 13) by clicking on the social media links provided in the interface. This possibility will be a great asset in forming a community of users around the core group of teachers more actively developing lesson plans. Thanks to the ease of use of the sharing tool, it is easy and intuitive for a teacher who has just created a new lesson plan to share it with colleagues or friends who can then adapt it to their specific needs, for example their national culture or curriculum and age-group of the students. Lesson sharing could also potentially be implemented (although it is more difficult to imagine due to timing issues) where for example if an ILS is based on the jigsaw scenario, student groups using the resource and taking part in the lesson could be physically placed in different classrooms or in different schools, allowing a level of exchange and learning that goes beyond the normal classroom experience.

Moreover, the rating and commenting functions which will be added to the lesson plans on a later development stage, will allow teachers to actively share their experiences and facilitate the other members of the community during their quest for appropriate, for their classes, lesson plans. This level of exchange and influence will benefit all members of the community while creating a supporting environment which will foster collaboration among its members.

The Go-Lab portal gives teachers the possibility to compare notes and share experiences about feedback received from their students on a particular ILS, through the ‘teacher notes’ section of the lesson plan.

Once a teacher creates a new lesson plan for an ILS based on, for example, the jigsaw approach, he can simply send the link of his lesson plan to the teachers’ community, or disseminate it through his Facebook page, to encourage colleagues to elaborate further on the model. This allows lesson plan creators to reach many potential users by publishing their resources on the platform. In turn, the teacher who chooses to build on his colleague's model can easily adapt the lesson plan to suits his own needs.

7 References

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of bloom's taxonomy of educational objectives*. New York: Addisson Wesley Longman.

Aronson, E. (2002). Chapter 10 - building empathy, compassion, and achievement in the jigsaw classroom. In J. Aronson (Ed.), *Improving academic achievement* (pp. 209-225). San Diego: Academic Press.

Barnett, R. M., K.E., J., Kourkoumelis, C., Long, L., Pequenao, J., Reimers, C., & Watkins, P. (2012). Learning with the atlas experiment at cern. *Physics Education, 47*, 28-37. doi: 10.1088/0031-9120/47/1/28

Bloom, B. S. (1956). *Taxonomy of educational objectives. Handbook I: The cognitive domain.* New York: David McKay.

Childs, P. (2012). Use of six hats in STEM subjects. from http://www.heacademy.ac.uk/assets/documents/stem-conference/Engineering1/Peter_Childs.pdf

de Bono, E. (1985). *Six thinking hats: An essential approach to business management*. New York, NY: Little Brown and Company.

de Bono, E. (2000). *Six thinking hats*. London: Penguin.

de Jong, T. (2006). Computer simulations - technological advances in inquiry learning. *Science, 312*, 532-533. doi: 10.1126/science.1127750

de Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340*, 305-308. doi: 10.1126/science.1230579

Forehand, M. (2005). Bloom's taxonomy: Original and revised. In M. Orey (Ed.), Emerging perspectives on learning, teaching, and technology. Retrieved from http://projects.coe.uga.edu/epltt/.

Funke, J., & Frensch, P. (1995). Complex problem solving research in north america and Europe: An integrative review. *Foreign Psychology, 5*, 42-47.

Garner, A., & Lock, R. (2010). Evaluating practical work using de bono's thinking hats. *SSR Science Notes, 91*, 16-18.

Gutwill, J. P., & Allen, S. (2012). Deepening students' scientific inquiry skills during a science museum field trip. *Journal of the Learning Sciences, 21*, 130-181. doi: 10.1080/10508406.2011.555938

Johnson, D. W., & Johnson, R. T. (2004). Cooperation and the use of technology. In D. H. Johanssen (Ed.), *Handbook of research on educational communications and technology* (2 ed., pp. 785-811). Mahwah, NJ: Lawrence Erlbaum Associates.

Johnson, R. T., Johnson, D. W., & Stanne, M. B. (1985). Effects of cooperative, competitive, and individualistic goal structures on computer-assisted-instruction. *Journal of Educational Psychology, 77*, 668-677. doi: 10.1037//0022-0663.77.6.668

Johnson, R. T., Johnson, D. W., & Stanne, M. B. (1986). Comparison of computer-assisted cooperative, competitive, and individualistic learning. *American Educational Research Journal, 23*, 382-392. doi: 10.3102/00028312023003382

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*, 63-85. doi: 10.1007/Bf02300500

Lou, Y. P., Abrami, P. C., & d'Apollonia, S. (2001). Small group and individual learning with technology: A meta-analysis. *Review of Educational Research, 71*, 449-521. doi: 10.3102/00346543071003449

Mäeots, M., & Pedaste, M. (in press). The role of general inquiry knowledge in enhancing students' transformative inquiry processes in a web-based learning environment. *Journal of Baltic Science Education.*

Mäeots, M., Pedaste, M., & Sarapuu, T. (2008, July 1-5). *Transforming students' inquiry skills with computer-based simulations.* Paper presented at the 8th IEEE International Confernce on Advanced Learning Technologies, Santander, Spain.

Mäeots, M., Pedaste, M., & Sarapuu, T. (2009, 16-18 March). *Developing students' transformative and regulative inquiry skills in a computer-based simulation.* Paper presented at the Proceedings of the IASTED International Conference on Web-based Education: The Eighth IASTED International Conference on Web-based Education, Phuket, Thailand.

Mäeots, M., Pedaste, M., & Sarapuu, T. (2011, 6-8 July). *Interactions between inquiry processes in a web-based learning environment.* Paper presented at the Advanced Learning Technologies (ICALT), 2011 11th IEEE International Conference on.

Manlove, S., Lazonder, A. W., & de Jong, T. (2009). Trends and issues of regulative support use during inquiry learning: Patterns from three studies. *Computers in Human Behavior, 25*, 795-803. doi: 10.1016/j.chb.2008.07.010

National Science Foundation. (2000). An introduction to inquiry *Foundations. Inquiry: Thoughts, views and strategies for the k-5 classroom.* (Vol. 2, pp. 1-5).

Pedaste, M., Mäeots, M., Leijen, Ä., & Sarapuu, T. (2012). Improving students' inquiry skills through reflection and self-regulation scaffolds. *Technology, Instruction, Cognition and Learning, 9*, 81 - 95.

Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., . . . Tsourlidaki, E. (submitted). Phases of inquiry-based learning: Definitions and inquiry cycle. *Educational Research Review*.

Reid, D. J., Zhang, J., & Chen, Q. (2003). Supporting scientific discovery learning in a simulation environment. *Journal of Computer Assisted Learning, 19*, 9-20. doi: 10.1046/j.0266-4909.2003.00002.x

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*, 257-285. doi: 10.1207/s15516709cog1202_4

Trowbridge, L. W., Bybee, R. W., & Powell, J. C. (2000). *Teaching secondary school science*. Upper Saddle River, NJ: Merrill / Prentice Hall.

van Joolingen, W. R., & de Jong, T. (1991). Supporting hypothesis generation by learners exploring an interactive computer simulation. *Instructional Science, 20*, 389-404. doi: 10.1007/BF00116355

van Rens, L. (2013a). *Methyl orange. Student workbook*. Amsterdam: FPP/VU.

van Rens, L. (2013b). *Methyl orange. Teacher's guide*. Amsterdam: FPP/VU.

Weinberger, A., de Jong, T., Dolonen, J., Hansen, C., Hovardas, A., Pedaste, M., . . . Matteman, Y. (2011). SCY scenario handbook and pedagogical plans, final version. Enschede: University of Twente.

Wu, H. K., & Hsieh, C. E. (2006). Developing sixth graders' inquiry skills to construct explanations in inquiry-based learning environments. *International Journal of Science Education, 28*, 1289-1313. doi: 10.1080/09500690600621035

Zacharia, Z. C., Xenofontos, N. A., & Manoli, C. C. (2011). The effect of two different cooperative approaches on students' learning and practices within the context of a webquest science investigation. *Educational Technology Research and Development, 59*, 399-424. doi: 10.1007/s11423-010-9181-2

Appendix A – full description of lesson plans

Electric circuit – In series and in parallel set-up

ABOUT THE LESSON PLAN

Go-Lab metadata:

ILS Title: In series and in parallel set-up

ILS Description: The basic idea of the lesson plan is to familiarize the students with the elements that compose a simple electric circuit (as well as electric circuits in general) and enable them to formulate an operational definition. The students will be introduced to both parallel and in series circuit set-ups.

Subject Domain: Electricity, direct current, simple electric circuit, in series circuit, in parallel circuit

Keywords: simple electric circuit, in series set-up, in parallel set-up, brightness, electric current, flow

Language: English

Grade Level: Upper secondary education (15-16 years of age)

Average time of use: 2 didactic hours (2 x 45 minutes)

Educational Objectives (Types of knowledge):

Factual: Learn about the differences between in series and in parallel circuits.

Conceptual: Formulate operational definitions of the simple electric circuit, in series and in parallel set-up.

Procedural: Construct a simple electric circuit with real material and design electric circuits using symbols.

Meta-cognitive: Reflect on the activities done and the results of the exploration.

Use of guidance tools and scaffolds: Notepad, calculator, twitter app, check spelling, concept mapping scaffold, questioning scratchpad

Additional metadata:

Scenario: Variation of basic scenario, Orientation – Question – Exploration – Data Interpretation – Conclusion – Reflection

Students' prior knowledge and skills:

- No domain knowledge is required since this is the first lesson on the unit of electricity.
- Basis ICT skills
- Basic inquiry and reflective skills in order to address the requirements of the activity

Organizational requirements:

- Computer lab (minimum 6 computers, one for each group)

Online Lab:

- Electricity Lab[7] (virtual lab)

[7] Electricity Lab was developed by Jakob Sikken (University of Twente)

ORIENTATION

<u>Materials</u>: 20 light bulbs, 20 bulbs wires, 20 batteries

<u>Tools</u>: Electric Circuit Virtual Lab, Concept map tool, Notepad

---

Step 1:

Based on your teacher's introduction on the topic of electricity, think possible ways to create a simple electric circuit mentioning the minimum number of elements needed.

Click on Assignment 1 below to provide your predictions whether the bulb is going to light up or not. Please make sure you save your answer.

Assignment 1

See the following arrangements carefully and predict if there is an electric current (the bulb lights up) and explain your reasoning.

	Would the bulb light up?	Explain your reasoning!
A) 		
B) 		
C) 		
D)		

		
E) 		
F) 		

 Get the materials from your teacher and check your predictions.

** You will need a wire, a bulb and a battery.*

 Discuss with your peers and teacher the cases in which the bulb lights up.

 Use the **Notepad** to describe a step by step procedure for the construction of a simple electric circuit.

**The above arrangements, in which the bulb lights up, will help you.*

**This is a description of a step by step procedure to identify the concept of mass. It might be helpful for your description.*
1. Take an object with unknown mass.
2. Place it on the one side of a scale.
3. On the other side place objects of the same kind, for example rubbers, until a balance occur.
4. You can argue that the mass of the object is equal to the number of the rubbers in the other side.

Did you run into any problems during your work with the physical materials?

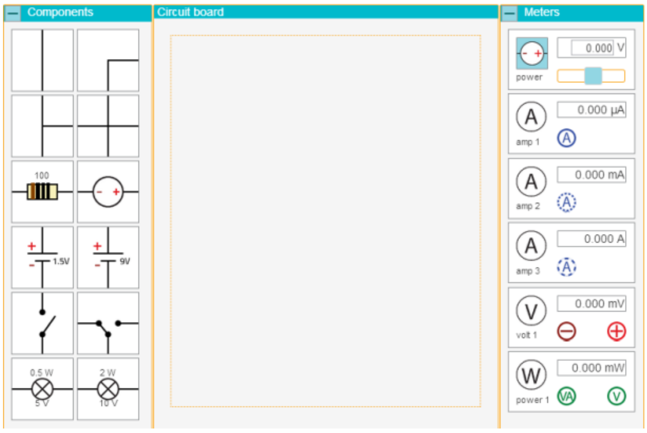
Discuss with your teacher and write your answer in the **Notepad**.

Step 2:

Now, familiarize yourself with the **Electric Circuit Virtual Lab** and explore the environment. You can discover the functions of the lab, its tools and the symbols used.

In order to practice create a simple electric circuit using the tool and try to switch between the symbolic and realistic view. What are the similarities and differences between the two views? Discuss with your teacher and classmates.

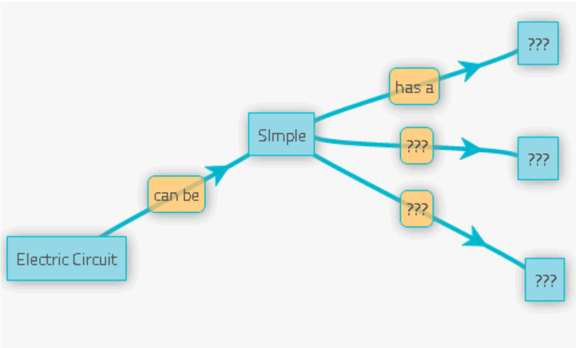
Electric Circuit Virtual Lab



Step 3:

Use the **Concept map tool** to create a concept map about the electric circuit taking into account the information you have learned until now. You can also add any other information you think is appropriate for your concept map.

Look at the image below (Concept map on electric circuit). This might be helpful for your concept map.



Notes for the teacher:

Encourage your students to participate in a discussion about electricity and simple electric circuits at the beginning of the lesson.

Do not point out mistakes concerning the domain, but try to create a fruitful discussion among students.

In order to help your students with the operational definition of the simple electric circuit, use the real materials and follow their instruction to create the circuit. This way, you will make them realize the importance of detailed instructions.

Do not point out mistakes concerning the construction of the concept map since students will revise it after the investigation phase. They must discover their own mistakes by the end of the lesson.

CONCEPTUALIZATION

Sub-phase: Question

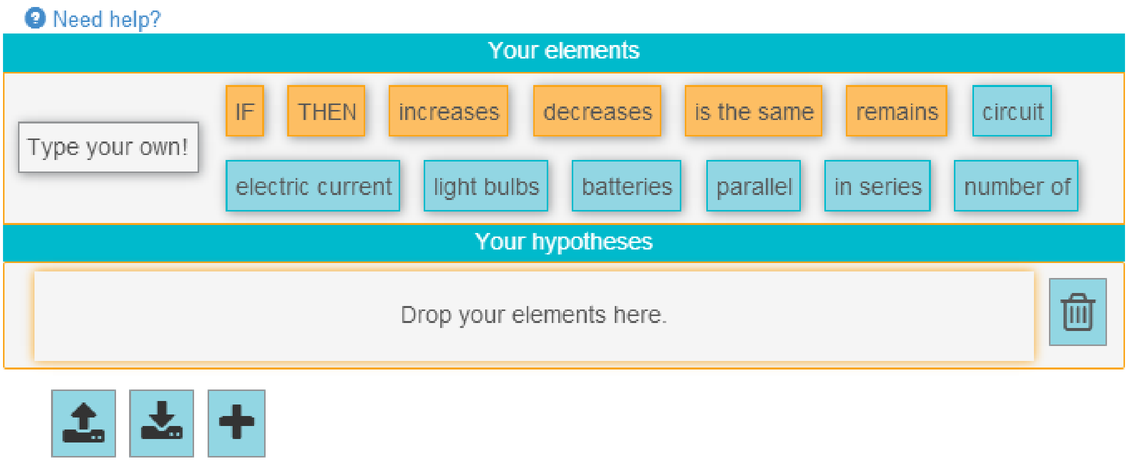
Tools: Questioning Scratchpad tool

Step 1:

Think of how it is possible to connect more than one light bulb on an electric circuit. Formulate a research question to address this problem in your groups.

Use the **Questioning Scratchpad tool** to formulate your research question.

Questioning Scratchpad tool



Step 2:

Now, based on your research question, share your ideas with your classmates.

Notes for the teacher:

Encourage your students to describe possible ways on how to connect two or more bulbs in an electric circuit and do not point out mistakes. Try to monitor the discussion between students and ask them to think critically. For example ask them: "What do think of what your classmate have just said? Do you agree or disagree? Why?"

Divide students into groups of 3-4 members. Explain to them that from now on they are going to cooperate in order to complete the learning activities.

If the available computers in your class are not enough, remind your students that they have to navigate to the environment alternately.

Provide a possible research question to your students if they have difficulties formulating one. For example, "How we can connect more than one bulb in an electric circuit?" "How more than one bulb can be connected to an electric circuit?"

INVESTIGATION

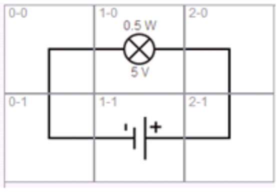
Sub-phase: Exploration

Tools: Electric Circuit Virtual Lab,

Step 1:

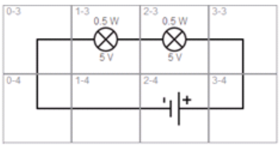
Complete the following tasks (1-9) to explore what is happening when you connect more than one bulb on an electric circuit, in parallel and in series. Use the **Notepad** to write your answers.

1. Create a simple electric circuit using the **Electric Circuit Virtual Lab**. Connect a bulb to the battery, as shown on the diagram A. What happens to the bulb?



A)

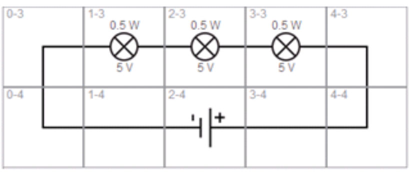
2. What do you think will happen if you connect two bulbs, as shown on the diagram B? Predict how the brightness of the two bulbs is compared?



B)

3. Construct the circuit shown on diagram B. Compare the brightness of these two bulbs, which are connected in series, with the brightness of the bulb of the circuit on diagram A. What can you observe about the brightness of the bulbs?

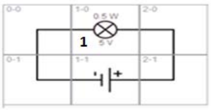
4. What do you think will happen if you connect three bulbs, as shown on the diagram C? Predict how the brightness of the three bulbs is compared?

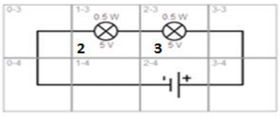


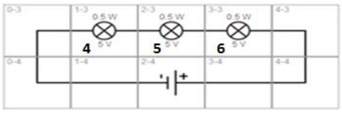
C)

5. Now, connect three bulbs in series with a battery to form a circuit as shown on diagram C. What can you observe about the brightness of the bulbs, as compared to the brightness of the bulbs of diagrams A and B?

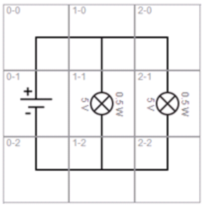
6. Put in order the light bulbs 1 to 6 according to their brightness, starting with the bulb with the less brightness.







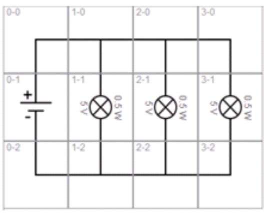
7. What do you think will happen if you connect two bulbs, as shown on the diagram D? Predict how the brightness of the two bulbs is compared?



D)

8. Connect two bulbs and a battery in parallel as shown on diagram D. Compare the brightness of these two bulbs with the brightness of the bulb of the circuit on diagram A. What do you notice about the brightness of the bulbs?

9. What do you think will happen if you connect three bulbs, as shown in the diagram E? Predict how the brightness of the three bulbs is compared?



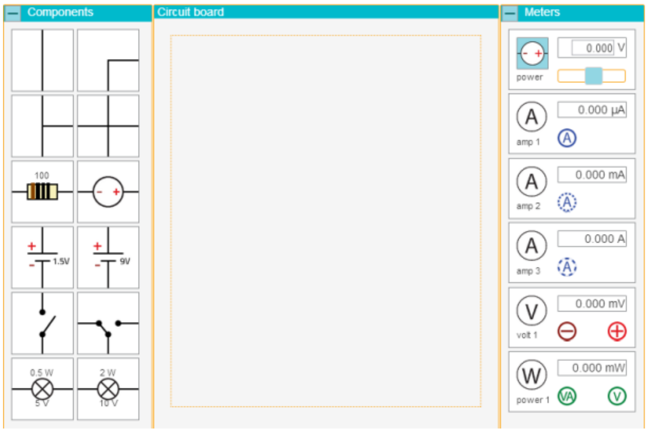
E)

10. Now, connect three bulbs in parallel as shown in the diagram E. What can you observe about the brightness of the bulbs? How does their brightness compare to the brightness of the bulb of the circuit on diagram A?

11. Remove the middle bulb from the circuit. What happens? What do you notice about the brightness of the remaining bulbs? How does the brightness of the remaining bulbs compare to the brightness of the bulbs of the circuits on diagrams A and E?

12. Compare the bulbs of all the circuits you have constructed so far. How does the brightness of their bulbs compare?

Electric Circuit Virtual Lab



Step 2:

Discuss with your teacher and peers your answers for each task.

> **Notes for the teacher:**
>
> Be ready to help your students face their difficulties during the circuits' construction with the Electric Circuit Virtual Lab.
>
> Be sure that all students in their groups write their answers in the Notepad. To help them more, ask them additional questions, if needed, to ensure that they understand correctly the whole process.

Sub-phase: Data Interpretation

The term **electric current** is used to refer to the flow of "something" that makes the bulb light in a closed electric circuit.

The brightness of the bulb is an indicator of the amount of the flow through the electric circuit.

Step 1:

Use the **Notepad** to formulate definitions for the parallel and series circuits.

Step 2:

Identify why the brightness of the bulbs differ in the parallel and in series circuits. In order to do that you have to refer to the flow of electric current. Use the **Notepad** to write your answer.

> **Notes for the teacher:**
>
> Guide your students during the formulation of the operational definitions concerning the information to be included.
>
> Encourage your students to refer to the operational definition of the simple electric circuit done previously.

DISCUSSION

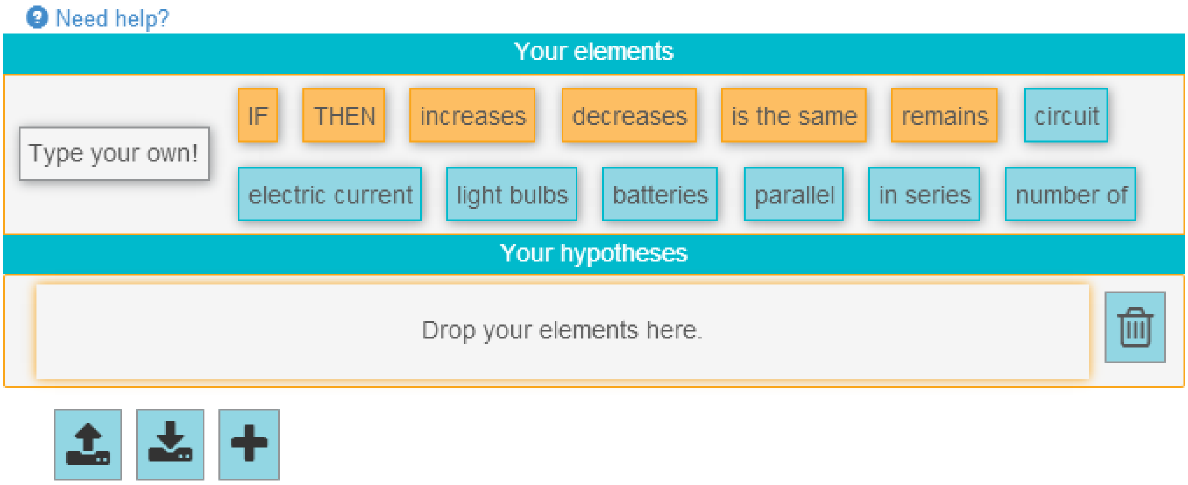
Sub-phase: Conclusion

<u>Tools</u>: Conclusion tool, Questioning scratchpad tool

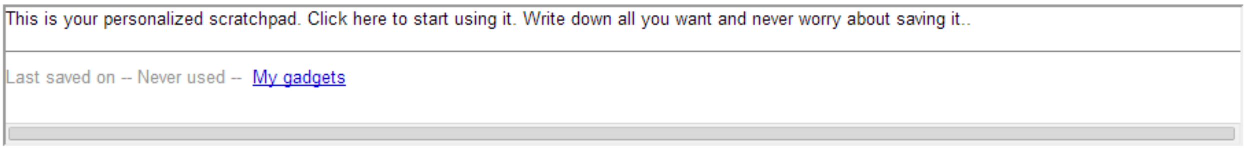
Step 1:

Use the **Conclusion tool** in order to write a complete answer for your research question. You can see your research question in the **Questioning Scratchpad tool** below.

Questioning Scratchpad tool



Conclusion tool



Sub-phase: Reflection

Step 1:

You have completed your exploration about in series and in parallel circuits. Your last task is to write your thoughts, in the **Notepad**, concerning the following:

- Describe what you explored in order to answer your research question.
- Are you satisfied with your answer?
- Think critically if you have completed all activities according to the guidelines.
- Evaluate your success in case of all phases of the learning process and in general.
- Consider alternative viewpoints for doing your work in a different way and identify activities that could be done similarly or differently.

Notes for the teacher:

Guide students during their reflection activity. Where necessary, formulate a question in order to help students address the reflection activities.

Electric circuit – Ohm's law

ABOUT THE LESSON PLAN

Go-Lab metadata:

ILS Title: Ohm's law

Brief Description: The basic idea of the lesson plan is to familiarise the students with the elements that compose a simple electric circuit (as well as electric circuits in general) and enable them to formulate an operational definition. Moreover, this lesson plan aims at guiding students to conduct scientific investigations in order to identify the concepts/variables involved in the domain of electric circuits. These concepts are: Current (I), Voltage (V) and Resistance (R). Given these concepts, students will be guided to understand the relationships between these concepts which lead to Ohm's law.

Subject Domain: Electricity, direct current, in series circuit, in parallel circuit, Ohm's law

Keywords: current, resistance, voltage, ammeter**,** ohmmeter, voltmeter, electric circuits

Language: English

Grade Level: Upper secondary education (15-16 years of age)

Average time of use: 2 didactic hours (2 x 45 minutes)

Educational Objectives (Types of knowledge):

Factual: Learn about Ohm's law.

Conceptual: Know the relationship between the electric current, voltage and resistance, and define the Ohm's law.

Procedural: Create a graphical representation of current and voltage and a graphical representation of current and resistance.

Meta-cognitive: Reflect on the activities done and the results of the investigations.

Use of guidance tools and scaffolds: Notepad, calculator, twitter app, check spelling, hypothesis scratchpad, experiment design tool

Additional metadata:

Scenario: Jigsaw approach

Students' prior knowledge and skills:

- No domain knowledge is required since this is the first lesson on the unit of electricity.
- Basis ICT skills
- Basic inquiry and reflective skills in order to address the requirements of the activity

Organizational requirements:

- computer lab (minimum 6 computers, one for each group)

Online Lab:

- Electricity Lab[8] (virtual lab)

[8] Electricity Lab was developed by Jakob Sikken (University of Twente)

ORIENTATION

Tools: Electric Circuit Virtual Lab

Step 1:

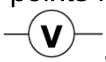
In this lesson you will further investigate how the current changes when circuit's elements are added in series and in parallel. Before you move on with your investigations, you have to read carefully the text below about important concepts you will need later on.

A simple electric circuit is comprised of a battery, a bulb and a wire. The flow of electric current, in a closed electric circuit, causes the bulb to light up. The brightness of the bulb is an indicator of the amount of the flow through the circuit. The brighter the bulb, the greater the amount of the flow.

An **Ammeter** is used to measure the magnitude of the **current** (I) that flows through an electric circuit and through each element of the circuit. The unit of measurement is an ampere (A). The ammeter symbolic representation is 

.

An **Ohmmeter** is an instrument that measures electrical **resistance** (R). The unit of measurement for the resistance is ohms (Ω). The symbolic representation of the ohmmeter is .

A **Voltmeter** is used to measure the voltage of an electric circuit. **Voltage** (V) is the potential difference in charge between two points in an electric field, measured in volts (V). The symbolic representation of the voltmeter is 

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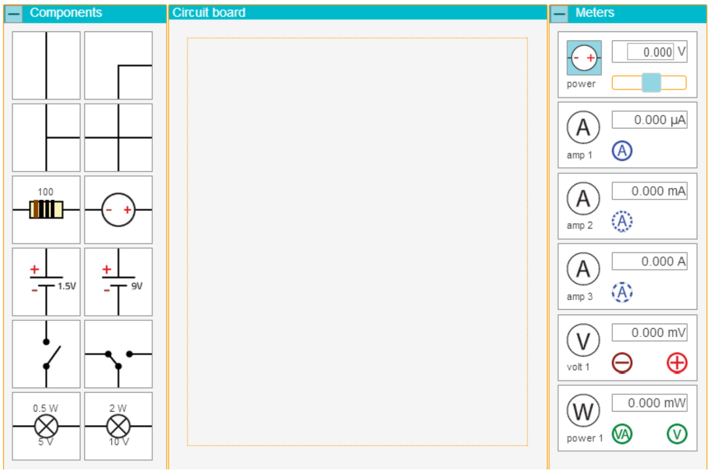
Step 2:

Use the **Electric Circuit Virtual Lab** to familiarize yourself with the meters. In order to practice, create a simple electric circuit and use the different meters, one at a time, to take some measurements. Move the meters around to investigate whether the measurements change.

Electric Circuit Virtual Lab



Notes for the teacher:

At the beginning of the lesson encourage your students to read the information. Introduce the Electric Circuit Virtual Lab to the students informing them about the function, the tools and the symbols.

CONCEPTUALIZATION

Sub-phase: Hypothesis

Tools: Hypothesis scratchpad tool

Step 1:

Now, ask your teacher to inform you about the element (bulb or battery) your group is going to investigate and how it affects the current of the electric circuit.

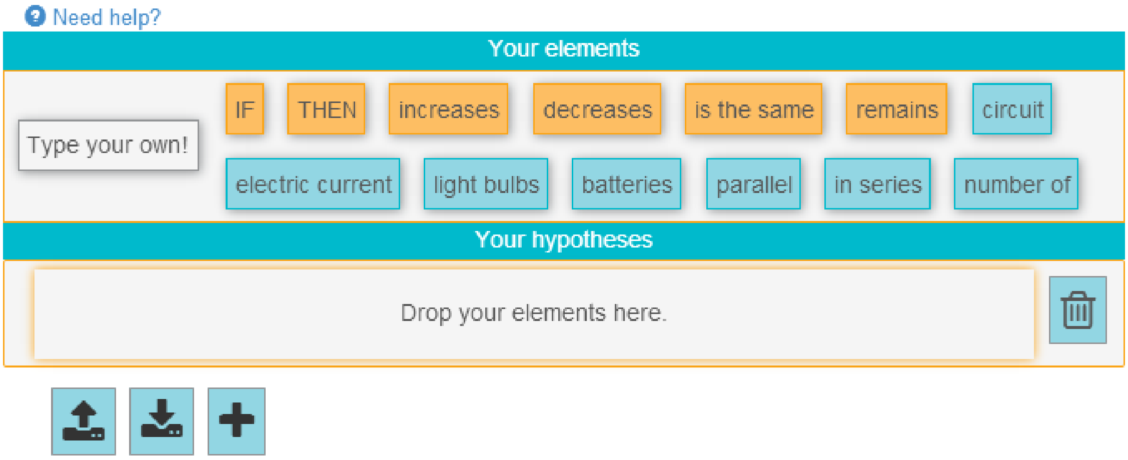
Then, form expert groups. Each expert group is going to specialize on a different set-up. For example, if your group is consisted of 4 members, two of you will specialize on the parallel set-up and the other two on the in series set-up. Your teacher will provide more instructions on how to form your expert groups.

Step 2:

Formulate your hypotheses according to your expert specialization. In order to do this, use the **Hypothesis Scratchpad tool**.

- A good hypothesis can be formulated in the form of "If ... then..." statement, which will investigate one dependent variable with at least one independent. For example, "If the independent variable increases, then the dependent variable decreases."
- Use only one dependent variable at a time when you formulate a hypothesis.
- Remember that a hypothesis might not be confirmed after the experimentation. This is not a problem. Many scientific experiments have led to valuable knowledge because they resulted in the rejection of a hypothesis.

Hypothesis Scratchpad tool



Notes for the teacher:

Inform your students that half of the groups will manipulate the numbers of light bulbs in their investigation and the other half, the number of batteries. Then, assign students of each group into expert groups, according to the jigsaw approach. The two specializations are the parallel and in series set-up.

Introduce the hypothesis scratchpad tool to the students and guide them during the formulation of their hypotheses to the tool. Give to the students a good hypothesis in order to learn to construct a testable hypothesis. A good hypothesis is a statement in the form “If….then…”. For example “If the A decreases then the B decreases.” Encourage students to pay attention to hints provided to them.

When the students in their expert groups are ready to formulate their hypotheses, ensure that they use the appropriate terms (variables) according to their specialization

INVESTIGATION

Sub-phase: Experimentation

Tools: Experimental design tool, Electric Circuit Virtual Lab, Hypothesis scratchpad tool

Step 1:

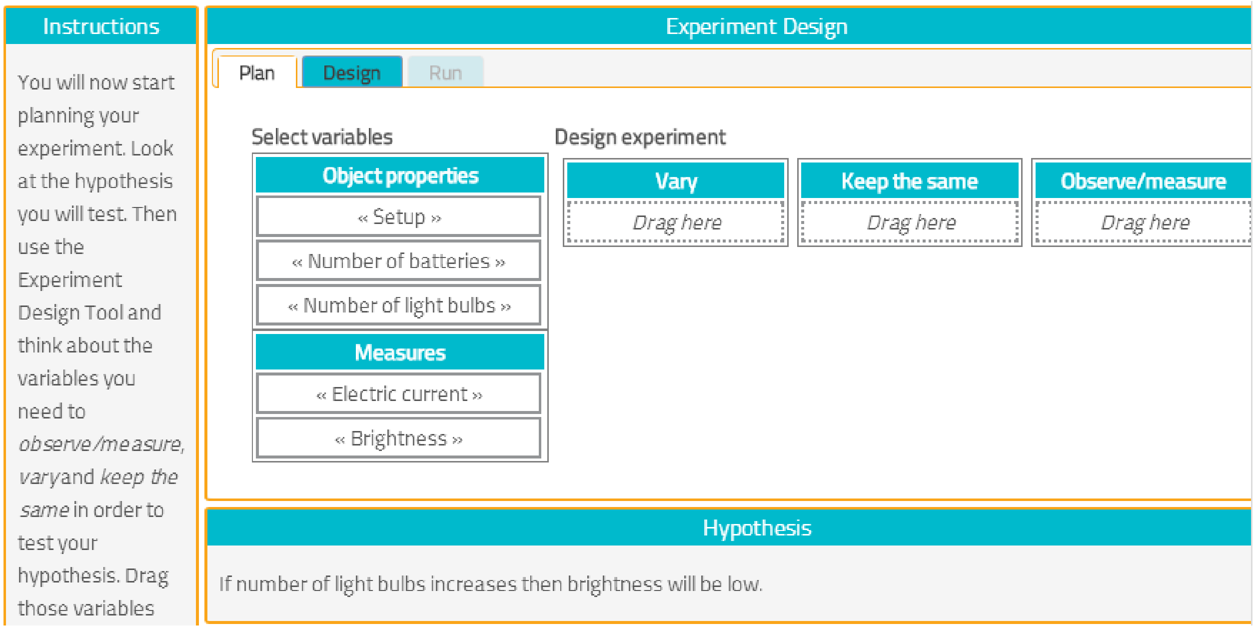
Discuss with your teacher and peers how you will carry out your experiment in order to confirm or reject your hypothesis.

Step 2:

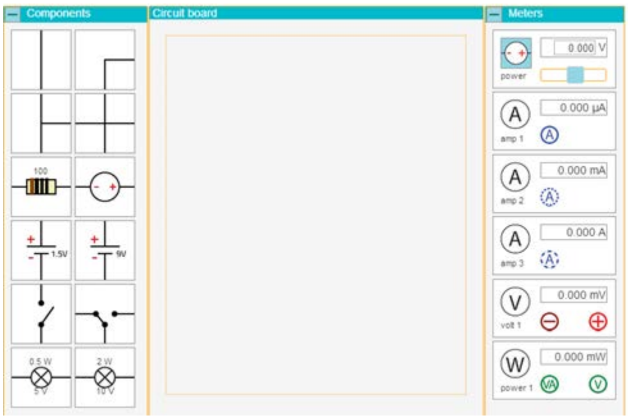
Now, you are about to design and conduct your experiments with the **Experimental Design tool** and carry them out in the **Electric Circuit Virtual Lab.**

- *Be careful to vary only one variable at a time.*
- *Keep record of your data in a table.*

Experimental Design tool



Electric Circuit Virtual Lab



Notes for the teacher:

During the discussion, encourage your students to describe the experimentation procedure of their investigation. Also, encourage them to comment about the procedures of their classmates. Guide your students during their experimentation activities by asking them reflection question. For example, ask them "Have you done all the necessary manipulations before you run the experiment?"

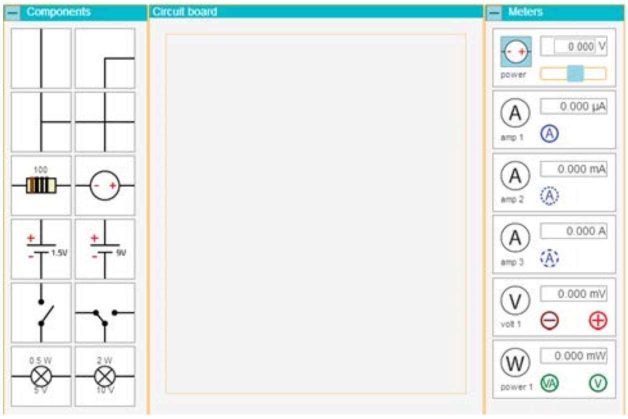
Sub-phase: Data Interpretation

Tools: Data interpretation tool, Electric Circuit Virtual Lab, Hypothesis scratchpad tool

Step 1:

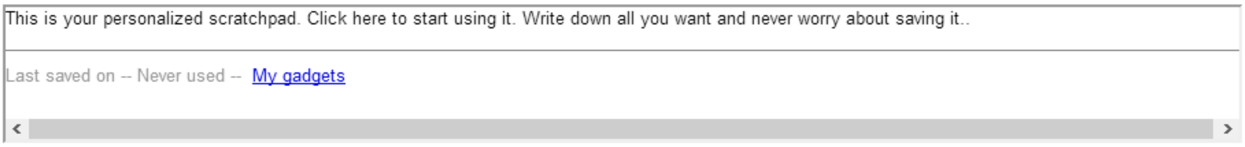
Use the **Data Viewer** of the **Electric Circuit Virtual Lab** to create a table with all the measurements you recorded for the independent and dependent variables of each of your hypotheses. It is also helpful to represent your data in graphs.

Electric Circuit Virtual Lab



Step 2:

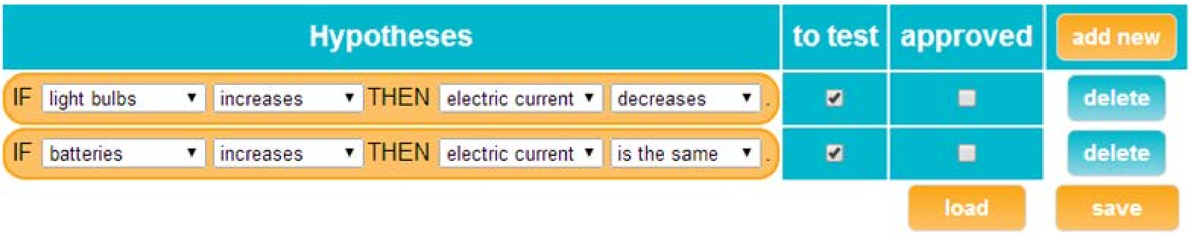
Interpret your data trying to find relations among variables using the **Data Interpretation tool**. If you don't have enough data, return to the Experimentation phase and collect more data.



Step 3:

Based on your data confirm or reject your hypotheses in the **Hypothesis Scratchpad tool**.

Hypothesis Scratchpad tool



Notes for the teacher:

Guide your students during their analysis, be prepared to introduce different strategies for data analysis and verification.

If your students do not have enough data in this phase, encourage them to go back to the experimentation and collect more data. Encourage your students to make graphical representations. They must have at least a graphical representation, for example, current vs voltage.

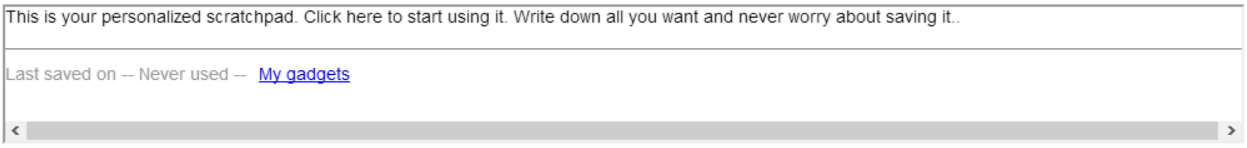
CONCLUSION

<u>Tools</u>: Conclusion tool

Step 1:

Use the **Conclusion tool** in order to form your conclusions based on your expert investigations.

Conclusion tool



Step 2:

Did you ever wonder if you could become a scientist? Discuss with your teacher and classmates whether you like the scientific process of experimentation.

Notes for the teacher: Guide your students during their activities in order to form valid conclusions. Point out flawed conclusions and encourage the students to repeat their experiments in order to come to the correct conclusion. During the second activity (step 2), discuss with your students how their work and outcomes can be applied in different careers. Refer to the way a scientist works: formulates hypotheses, runs experiments, collects, analyses and interprets the results, forms conclusions and communicates his/her findings.

DISCUSSION

Sub-phase: Reflection

Step 1:

In your expert group discuss the following:

- Describe what you did in your expert group.
- Think critically if you had completed all activities according to the guidelines.
- Evaluate your success in all phases of the learning process and in general.
- Consider alternative viewpoints for doing your work in different ways and identify activities that could be done similarly or differently.

Use the **Notepad** to write your thoughts/answers.

Notes for the teacher: Guide students during their reflection activity. Where necessary, formulate a question in order to help students address the reflection activities.

Sub-phase: Communication

Tools: Communication tool

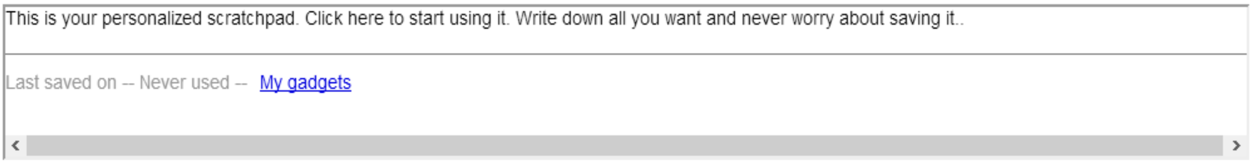
Step 1:

Return to your initial group in order to share your results with your teammates. Each expert must inform the other members of his/her team about their investigations and conclusions.

Step 2:

In your group you have to prepare a short presentation (5 min) of the conclusions of your investigations. In order to do that, use the **Communication tool**.

Communication tool



Step 3:

Present your conclusions to the other groups. When a presentation finishes, you can ask clarifying questions and/or make comments to your classmates.

Step 4:

Your teacher will introduce to you the Ohms' law and you have to judge whether this law is plausible, given your own findings (I vs. V and I vs. R).

Notes for the teacher:

Guide students when they prepare their presentation. Encourage students to have a discussion during the presentations and make comments to each other.

Introduce Ohms' law to your students and encourage them to judge whether the law is plausible based on their findings.

Conservation of momentum

Go-Lab metadata:

ILS Title: Conservation of momentum

ILS Description: Students will determine the total momentum from all particles tracked after a particle collision and they will calculate the missing momentum(magnitude & direction).

Subject Domain: : Accelerators & beams, Calorimeters, Particle beam parameters, Particle detectors, Angular velocity, Collision, Conservation of momentum

Keywords: mass, velocity, acceleration, energy, momentum, collision, conservation of momentum, radians, degrees, vector

Language: English

Grade Level: Upper Secondary Education (15 -18 years old)

Average time of use: 3 didactic hours (2 x 45 minutes)

Educational Objectives (Types of knowledge):

Factual: Learn about the conservation of momentum.

Conceptual: Get acquainted with particle physics research

Procedural: Learn how to add vectors, Measure vector angles and convert radians to degrees of angle

Meta-cognitive: Learn how to process real scientific data from the ATLAS experiment

Use of guidance tools and scaffolds: scratchpad, calculator, hypothesis scratchpad, concept map

Additional metadata:

Scenario: Variation of basic scenario, Orientation – Hypothesis – Experimentation– Data Interpretation – Conclusion – Reflection

Students' prior knowledge and skills:

- Background knowledge in Newton's Law's, momentum, mathematical vectors
- Basis ICT skills
- Basic inquiry and reflective skills in order to address the requirements of the activity

Organizational requirements:

- Computer lab (minimum 6 computers, one for each group)

Online Lab:

- HYPATIA (Data Set/Analysis Tool)[9]

Orientation

a. The LHC@CERN

The Large Hadron Collider (LHC) is a gigantic scientific instrument near Geneva, where it spans the border between Switzerland and France about 100m underground. It is a particle accelerator used by physicists to study the smallest known particles – the fundamental building blocks of all things

CERN in 3 minutes

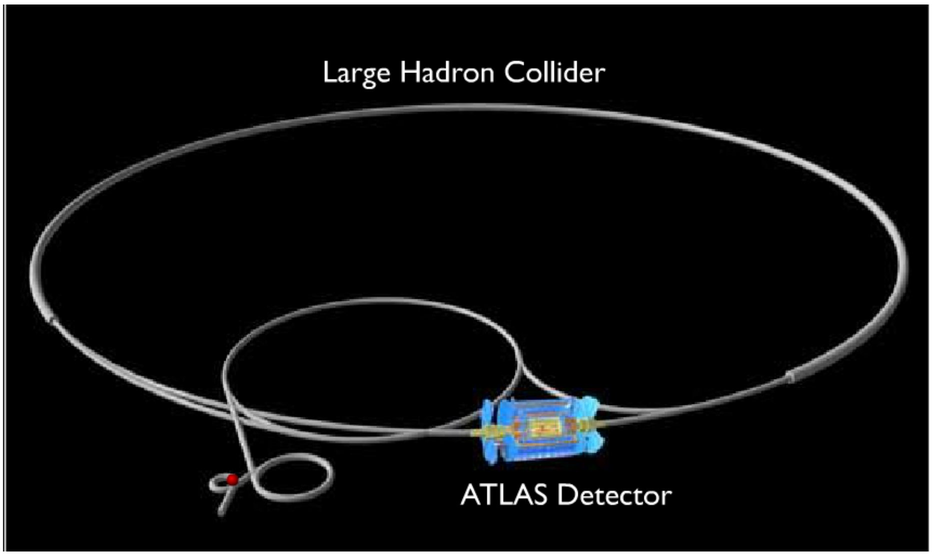
http://www.youtube.com/watch?v=3wtUr3iVVIw)

Two beams of subatomic particles called 'hadrons' – either protons or lead ions – will travel in opposite directions inside the circular accelerator, gaining energy with every lap. Physicists will use the LHC to recreate the conditions just after the Big Bang, by colliding the two beams head-on at very high energy. Teams of physicists from around the world will analyse the particles

[9] HYPATIA was developed by a team of authors, see Barnett et al. (2012).

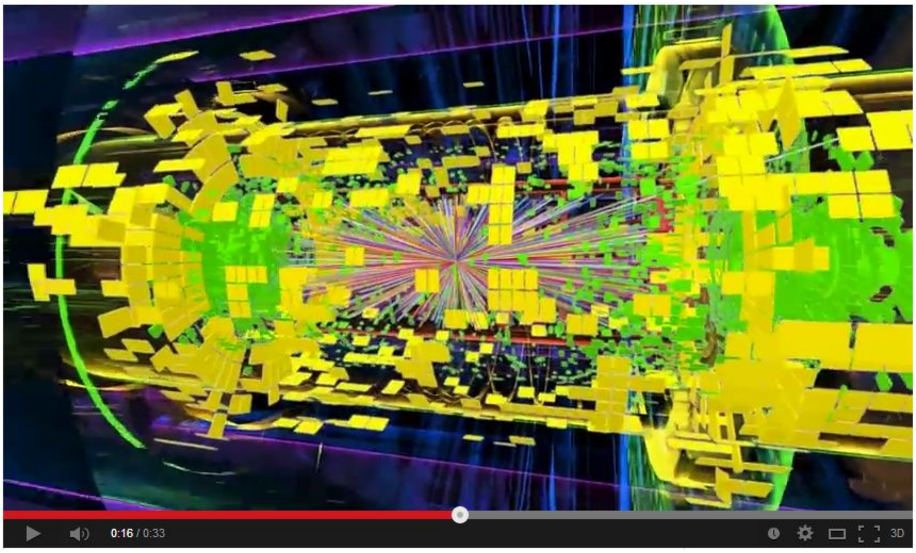
created in the collisions using special detectors in a number of experiments dedicated to the LHC.

The Large Hadron Collider



http://hands-on-cern.physto.se/ani/acc_lhc_atlas/lhc_atlas.swf

Heavy Ion Collision Event Animation



http://www.youtube.com/watch?v=k64s4Ho-8-I

- What do you know about the work done at CERN?
- What are the experiments performed trying to achieve?
- What happens during the particle collisions that take place in the LHC?

Notes for the teacher:

You may begin your lesson with a brief presentation of CERN and the Large Hadron Collider using videos or numerous pictures. Trigger a small conversation with your class by asking your students the questions mentioned above and others like them. You may find additional information on LHC in the "The LHC brief description" document. Try to guide the discussion towards the introduction of the elementary particles.

Conceptualization

b-phase: Hypothesis

Let's see what we already know about particle collisions!

Step 1:

1. Does the momentum depend on the direction of the velocity?
2. What is an isolated system?
3. What does “conservation of momentum” really mean?
4. Does the kinetic energy need to be conserved in collisions?
5. How are elementary particles classified?
6. When particles collide are new particles created or not?

Create a map which includes all the concepts that are relative to particle collision in the LHC. Use arrows to connect the different concepts.

Step 2:

Scientists at CERN analyse the data they get from particle collisions done in the LHC in order to answer their scientific questions. We will now put ourselves in the shoes of scientists and we will learn how they process their data. Our work will involve the studying of some events from the ATLAS detector. But first, we will have to set our own scientific questions. Read the questions below and make your hypotheses. Make sure to write down your hypotheses in a notebook because our research will be based on them.

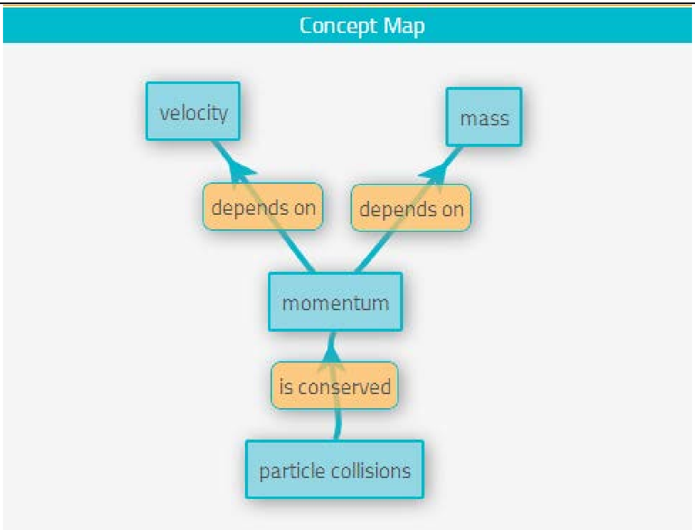
- Does the conservation of momentum also apply to the plane perpendicular to the beams’ direction (x-y plane) during particle collisions?
- How can we measure the total momentum in such collisions in the x-y plane?
- If we measured the total momentum on the x-y plane after a collision what to you expect to find?

Notes for the teacher:

Step 1:

During your discussion with students on the issues mentioned above make sure to ask scientifically oriented questions like the ones mentioned above to further engage them. Thus, the related theory will mainly be presented by students and the teacher only adds information when needed. In the “Related theory” document you may find additional information on the theory involved in this activity.

An example concept map could be the following:



Step 2:

You may inform your students about what they will do during this exercise:

- Learn about the conservation of momentum
- Learn how to process the data provided by the ATLAS experiment.

Do not point out any mistakes students might make. Students are supposed to discover these mistakes themselves and correct them. Alternatively, you may note them down and bring them back to their attention at a later stage.

Investigation

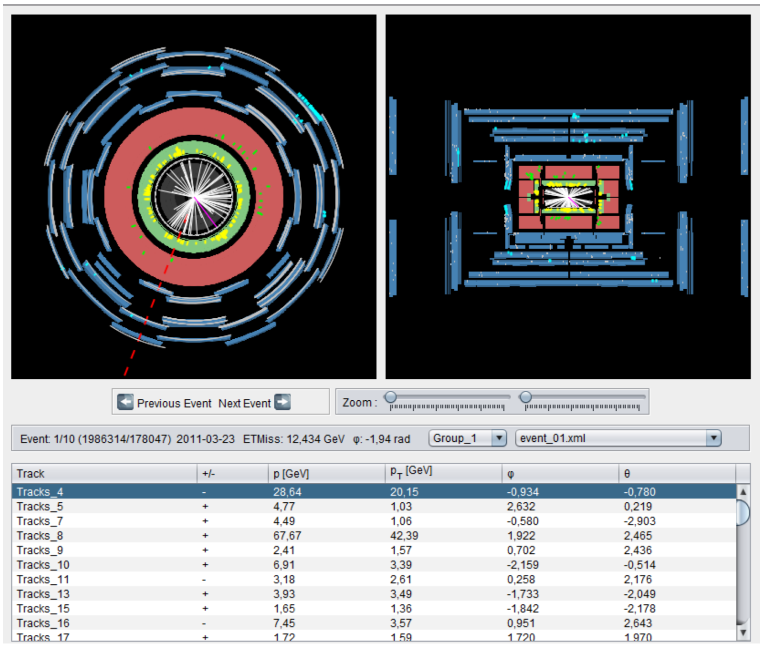
You can divide your students into groups of four students.

Sub-phase: Experimentation

Step 1:

Before we get started with our research let's have a look at the lab we are going to use. The lab that will help us perform our research is called HYPATIA and it is an analysis tool designed to analyse real data obtained from the ATLAS experiment carried out on the LHC at CERN.[10] Visit the "HYPATIA_Instructions" document to read about the lab.

[10] The development of HYPATIA is described in Barnett et al. (2012).



Step 2:

1. Select event file 'event_14.xml' (use buttons "Previous Event" and "Next Event") from the "Higgs" group of data to view the data from the collision under investigation.

2. Look at the data in the table below the detector. Try to understand to which track depicted in the detector each line of data belongs to.

3. In order to calculate the total momentum of the collision you will need to draw the vector of each particle. To do that, we must first identify the magnitude and the angle of each vector.

For each particle, the angle of the vector is the angle (φ) which is depicted in radians.

The magnitude of the each vector is the value in column P[GeV]). Use the table below to keep note of your data.

Track Name	Particle Identity	Angle in degrees	Normalized magnitude

Before you draw your vectors you must make sure you are using the correct values. To this end pay attention to the 2 tips mentioned below*.

a. The angle is depicted in radians. In order to draw the vector you must first convert the angles in degrees.

b. In order to be able to draw the vectors they must all be drawn to scale. In order to do this you must normalize your values. Divide all measurement for the momentum with the lowest value and fill in the respective column of your table.

4. Based on your calculations above draw the respective vectors.

Notes for the teacher:

The main idea of the exercise is for students to discover a missing particle based on the conservation of momentum using the HYPATIA analysis tool. In any particle collision like those under investigation the final total momentum on the x-y plane (the plane perpendicular to the direction of the two beams) is expected to be zero. Students will be asked to measure this total momentum after a collision and verify this fact. However the total momentum which they will calculate will not be zero which must lead them to the conclusion that an extra particle was created during the collision, whose track could not be detected by the instruments. In order for the momentum to be conserved this missing particle (which is a neutrino) must have momentum equal to the total momentum calculated by the students and of opposite direction.

You may choose to divide the class into groups in order to do the experimentation.

Students also have the tendency to change variables in an uncoordinated way. Guide them so as to make their investigation as systematic as possible by changing only one variable at a time and by keeping notes not only for their data but also about the process itself.

*You may choose not to provide the students upfront with the two tips mentioned above, and mention them only after they have faced the problem of how to draw the vectors.

Tip: Make sure students understand the connection between the investigation and the hypotheses they have made. In other words make sure they understand why they are doing every single step.

Sub-phase: Data interpretation

Now use the data you have collected to make some further investigation.

1. Study the tracks and note down in your table what kind of particle you believe each track belongs to. Explain why you made each choice.

2. Based on the vector analysis you did calculate the amount of total momentum and its respective angle. Make sure to use the original values and not the normalized ones.
3. Is the total momentum you calculated zero? If not, why is it not zero?

4. Draw the vector for the total momentum according to your estimation and the respective missing momentum vector. (Not exact solution)

Notes for the teacher:

You may find the answers of the questions in the “Teacher answer key” document.

Conclusion

Based on the experiment you conducted, answer the following questions. Note down your answers in order to produce your report.

1. Is the total momentum (the x-y plane) you calculated zero? If not, why is it not zero?

2. Does the conservation of momentum apply or not? If yes why is the total momentum you calculated non zero?

3. Does the vector for the missing momentum you drew match the vector presented in the detector?

4. What sources of error are there?

Now look back to your original hypotheses and compare them to your conclusions. Do your results agree with your conclusions? Identify any mistakes you might have made while making your hypothesis.

Notes for the teacher:

If you have noted any mistakes that the students made during the previous phases make sure to bring them up and discuss them with their students so they may understand what their mistakes was.

It is useful to point out to the students, that the real set of data for this event (and all other events) included thousands of tracks which are very very small. Scientists, in order to make the same calculations for the vectors (just like the students did) they use extensive computational programmes.

Discussion

Sub-phase 1: Communication

Make a brief report of your work so you can present your work to your fellow-students. In order to attract their attention try to be as creative as possible. You can do a small video out of it, a Prezi, a PowerPoint presentation or a poster like those presented by scientists during conferences.

Sub-phase 2: Reflection

Compare your results of your team used with those of other teams. Have you calculated the same total momentum?

Is there a possibility that other particles that have not been tracked might have been produced? Can you give examples?

Notes for the teacher:

Comment on your students results. Point out which are the strong parts of their work and which are the weak ones.

Finally ask your students to comment on the accuracy of the method followed.

You may also discuss with them about the Higgs boson, and how scientist are able to track it through data like the ones they used in this activity. For more information check here.

Buoyancy

Go-Lab metadata:

ILS Title: Buoyancy, Archimedes principle

ILS Description: Students work in groups and design and perform their own experiment about Archimedes' principle. The thinking hats are used to help guide the decisions the groups makes when creating and selecting research questions and hypothesis, designing experiments and drawing conclusion.

Subject Domain: Buoyancy, density, Archimedes principle

Keywords: Archimedes principle, buoyancy, density

Language: English

Grade level: Upper Secondary Education (14 – 18 years old)

Average time of use: 2 didactic hours

Educational Objectives (Types of knowledge):

Factual: Learn about mass, volume, density and fluid displacement

Conceptual: Learn how Archimedes principle influences situations

Procedural: Learn how to perform an experiment

Meta-cognitive: Learn how to approach situations from different perspective, practice parallel thinking

Additional metadata:

Scenario: Thinking hats

Students' prior knowledge and skills:

- Students need to be familiar with the concepts of mass, volume and density. They should have some experience with experimentation and some basic knowledge about what research questions and hypotheses are and how to draw conclusions

Organizational requirements:

- Students will work in groups of 3 or 4. The lesson will end with a discussion with the entire class.
- At least one computer per group of 3 or 4 students.

Online Lab:

- Splash[11] (virtual lab)

Introduction

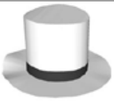
Six thinking hats

Six Thinking Hats is a method that teaches you parallel thinking. This method developed by Edward de Bono helps to separate thinking into six different functions and roles (E. de Bono, 1985). Each style of thinking is identified with a symbolic coloured 'thinking hat'. By wearing and changing hats groups are challenged to approach a situation from different perspectives.

[11] Splash was developed by Anjo Anjewierden (University of Twente).

You are going to use these thinking hats to guide your inquiry. But first you need some practice. Table 1 gives an overview of the six hats. Read them carefully and try to remember the meaning of each hat.

Table 1: Overview of the six thinking hats

	What do you know and what don't you know? What information do you need?	• Neutral • Data & facts • Known & unknown
	What are your feeling? What does your gut tell you?	• Emotions & feelings • Intuition & hunches • Don't justify
	What are the positives?	• Constructive • Optimism • Benefits & positives
	What are the negatives?	• Critical • Caution • Negatives & risks
	What other ways are there of doing this?	• Creativity & innovation • New ideas & possibilities • Alternatives
	What is the best way to control the process?	• Overview • Focus & goals • Control

Assignment 1

Which hat are Sara and Tom wearing?

Sara and Tom discuss the declining supply of petroleum fuels and use the thinking hats to guide their thinking. Read their conversation below and indicate after each sentence which hat they were wearing. Write down your answers in the notepad. You can find your notepad in your tool box. Try not to peek at the table!

1. Sara: '*Why do we need fossil fuels?*'
2. Tom: '*Most cars and trucks use fossil fuels.*'
3. Sara: '*Fossil fuels are also used to generate electricity.*'
4. Tom: '*They are made out of oil'.*
5. Sara: '*How much oil do we have left on the earth?*'
6. Tom: '*I don't know, we should look that up.*'
7. Sara: '*What will happen if there is nothing left? It's a scary idea.*'
8. Tom: '*There are plenty of alternatives for fossil fuels'.*
9. Sara: '*What alternatives can we think of, let's try to make a list'.*

10. Sara: *'We can use solar energy or wind energy'.*
11. Tom: '*Or nuclear energy'.*
12. Sara: '*Nuclear energy can be dangerous and we have to find a solution for all the nuclear waste'.*
13. Tom: *'But there is almost no remission of CO_2 and it is without end'.*
14. Sara: '*I don't like the idea of nuclear energy. I like solar energy better.'*
15. Tom: '*Solar energy is expensive though'.*
16. Sara: '*Many countries have tax benefits for people using solar energy.'*

You will now discuss your answers with your teacher and the rest of the class.

Now you know how to use the hats. In the next phase you will use the hats to guide your investigation.

Notes for the teacher:

You can discuss the answers in a classroom discussion to get an idea a well students comprehend the meaning of the different hats. If necessary you can give some extra explanations.

Orientation

Eureka, the story of Archimedes

2.200 years ago King Heron II of Syracuse ordered to make a golden crown. He supplied the jeweller with a bar of pure gold to make the crown. Though the crown was beautiful, the king wasn't pleased. He suspected that the jeweller had replaced some of the gold with silver, keeping the replaced gold for himself.

The king had no idea how to proof his suspicions, so he asked Archimedes for help. Archimedes, a Greek mathematician, had to solve the problem without damaging the beautiful crown. Melting it down in to a regular shape, so he would be able to calculate its volume and density, was thus not an option.

Archimedes thought about the problem for weeks, but could not solve it. Until one day, while taking a bath, he noticed that the water in the bathtub rose as he got in. Suddenly he had an idea how to solve the problem. Archimedes was so excited by his idea that he jumped out of the bath and run to the streets naked, crying 'Eureka'!

What did Archimedes find out? You will find out during the following assignments.

Your teacher will divide you into groups of 3 or 4. When you use thinking hats in your assignments, all group members wear the same hat at the same time. So when you use the white hat, every team member is wearing a white hat.

<u>Assignment 2</u>

 *Put on your white thinking hats*

What do you already know about Archimedes' principle? Try to think of as many concepts as you can and create a concept map. Don't forget to use the variables that are mentioned in the story above, for instance the concept volume. Use the concept map tool.

Now watch the video about Archimedes' principle. Use what you learn to improve your concept map.

http://www.youtube.com/watch?v=ijj58xD5fDI

Notes for the teacher:

Some students might need some help to get going. You can choose to make an example concept map to get them going, or to discuss with them at the end of the assignment. This will make sure that all students have the crucial elements incorporated in their concept maps.

Conceptualization

Sub-phase: Questioning

Assignment 3a

 *Put on your green thinking hats*

Try to think of as many research questions as you can. A research questions asks for the effect of a certain variable. For example: “What is the effect of mass on the sinking or floating behaviour of an object?”

You are wearing your green hats, so try to be creative. Don't worry if your questions are good enough, just think of as many questions as you can. Use the questioning scratchpad.

Take a look at the virtual lab Splash, which you will be using for your investigation. You can find it at the bottom of this page. You will perform you investigation in the ‘Archimedes' tab.

Take 5 minutes to play around and find out what is possible in the lab. Then go to assignment 3b.

Assignment 3b

 Now put on your yellow thinking hats, then put on the black one

Put on your yellow hats and look at your questions. Why are these good questions? Then use the black hat and be critical. Are they all good research questions, or are some of them less suitable? Can you answer these questions using the Splash lab? And is it easy and practical to design an experiment to investigate your questions using the lab?

Choose the best questions in your list. If there is more than one, use the one that the group finds the most interesting.

Notes for the teacher:

In the first assignment 3a, students have to think of as many questions as they can. In this assignment it is not important if they are good questions, so don't critique any questions the students come up with, but save any comments for assignment 3b.

In assignment 3b students might need some help to determine what a good question is and what not. If necessary, you can give a short classical explanation about what research questions are and what qualities are required for a good research question. Also make sure to explore the Splash lab, so you know which research question can or can't be investigated with this particular lab. You might want to guide students a little when they choose a question, to make sure the next phase will go smoothly.

Walk around and check if the groups are using the thinking hats correctly. The entire group should wear the same hat at the same time. Interfere when necessary, some groups may need some extra guidance.

Sub-phase: Hypothesis

Assignment 4


First put on your red thinking hats, then put on the black one

When you formulate a hypothesis, you not only indicate which variable you want to investigate, but you also give a prediction about the direction of an effect. If we make a hypothesis for our question: "What is the effect of mass on the sink or float behaviour of an object?" we need to give a prediction about the effect of mass. For example a hypothesis could be: "If the mass of an object increases, an object will sink." Or the other way around: "If the mass of an object decreases, an object will sink."

Put your red hats, use your intuition to predict the effect of the variable in your question and formulate one (or more) hypothesis. Then put on your black hat and look critically at your hypothesis. Is it feasible to investigate this hypothesis? Will you be able to find a reliable and valid answer?

Notes for the teacher:

Just like the previous phase students might need some help to determine what is a good hypothesis is and what not. If necessary, you can give a short classical explanation.

Also make sure that students use the thinking hats correctly. The red hat should only be used for a very short amount of time. The emphasis should be on the black hat, to stimulate critical thinking.

Investigation

Sub-phase: Experimentation

You will now investigate your hypothesis in Splash. First use the experiment design tool to set-up a structured experiment and then execute it in Splash. Process your information in the analyses tab of the lab.

Assignment 5

Use the experiment design tool below to plan your experiment.

Assignment 6

 Put on your blue hats during experimenting and data-analysing. Use both your blue and your white hats during analysing.

You will now investigate your hypothesis using the Splash lab. You will only use the Archimedes tab and the analysing tab of the lab. Use your thinking hats well! The following questions can help you along:

Use the blue hat to control your process:

- What is the next step in our investigation?
- Do we get the information we need this way?
- How do we proceed analysing our data?

Use your white has to check your data:

- What kind of data did we collect?
- Which data is still missing?
- Is this data valid and reliable?

Notes for the teacher:

Students should be able to execute this phase on their own pretty well. Do make sure that they collect all the data they need. If possible you might want to make sure that every student has his or her own computer, so they all get some experience with the virtual lab.

Sub-phase: Data interpretation

Students will analyse the collected data in the analysing tab of Splash.

Notes for the teacher:

Depending on the knowledge and skills of your students you may choose to perform the analysis with the entire class. Determine what kind of data you expect from you students, for example table, a graph, certain calculations. This can depend on the level of your students. Also make sure that all students participate in this activity, not only the best students. Every student should get a chance to offer his or her input and all students should comprehend the performed analysis. Intervene when necessary.

Conclusion

In this phase you will use the collected data to come to a conclusion. Can you answer your research question? And was your hypothesis correct?

Assignment 7

 *First put on your white hats, then the black ones.*

Draw conclusions based on your data:

- Use your white hat to look at the information you have collected. What did you learn? Did you get an answer to your question?
- Use the black hat to look at your conclusions. Are they valid and reliable?

Note everything in your notepad.

Notes for the teacher:

Give students some times before pointing out any invalid conclusion. Give them a chance to discover these mistakes themselves wearing the black hat.

Discussion

Sub-phase: Reflection

In this phase you will reflect upon your lesson. Afterwards you will present you findings to the rest of the class.

Assignment 8

 Put on your red hats, then the yellow ones, the black ones and end with the green ones.

Reflect with your group on the lessons of today. Discuss your approach, your cooperation, the tools and the labs. Note everything down in your notepad.

- First put on your red hats to explain what you feel. Was it fun/ annoying/ interesting/ difficult/ easy etc.?
- Put on your yellow hats to discuss what went right.
- Put on your black hats to discuss what didn't go so well.
- Put on your green hats to think what you could have done differently? Do you think you learned enough and how could you improve that? How can you make the lesson more interesting and fun?

Notes for the teacher:

You might choose to perform this activity with the entire class, instead of in groups. Be very alert if the hats are used in the correct manner. All students should wear the same hat at the same time and all students should be able to attribute something for every hat they are wearing.

Limit the amount of time students wear the red hat, for example to five minutes in total. This will prevent students from just endlessly complaining and forces them to focus on the other hats and reflect more deeply.

Sub-phase: Communication

Present your findings to the rest of the class. Make sure to include all phases in your presentation, beginning with orientation and ending with reflection. Your presentation should be about 10 minutes long. Your whole group should be in front of the class and everyone should present part of your presentation.

You don’t have to include the thinking hats in your presentation, though you can if you really want to. Try to focus on the result of all phases and sub-phases.

Notes for the teacher:

Choose a presentation form that suites your students and your lesson. This can be a written report as well, if you feel this will feed your needs better. When making a presentation, you could choose to use PowerPoint.

Make sure students focus on the results of each phase, they don't have to explain their entire process during each phase. They don't need to use the thinking hats in their presentations.

You might end with a classroom discussion to check if all students gained the domain knowledge about Archimedes principle that you aimed for. If not, the best groups can help the other groups to get this knowledge as well.

Galaxy Classification and Formation

Go-Lab metadata:

ILS Title: Galaxy Classification and Formation

ILS Description: The following exercise aims to introduce to students the concept of varying galactic morphologies. Students will look in detail at images of numerous galaxies and they will attempt to classify them according to the Hubble Classification Scheme. Moreover, the class will try to investigate the origin of the shapes of the galaxies that stem from galaxy interactions.

Subject Domain: Elliptical galaxy, Formation, Galaxies and Dwarf galaxies, Spiral galaxy, Irregular galaxy, Gravitational field, Collision, Gravitational force and gravity, Velocity, Universal law of gravitation

Keywords: galaxies, spiral, elliptical, irregular, gravity, formation, interaction, tuning fork, classification

Language: English

Grade Level: Primary Education (10 -12 years old)
Lower Secondary Education (12 -15 years old)
Upper Secondary Education (15 -18 years old)

Average time of use: 3 didactic hours (2 x 45 minutes)

Educational Objectives (Types of knowledge):

<u>Factual</u>: Learn about the different shapes of galaxies and about the Hubble classification system.

<u>Conceptual</u>: Learn about the concept of gravity, how galaxies interact and how they are formed.

<u>Procedural</u>: Learn about simulations and how they may be used in a scientific context.

<u>Meta-cognitive</u>: Get acquainted with making and studying astronomical observations.

Use of guidance tools and scaffolds: scratchpad, calculator, hypothesis scratchpad, concept map

Additional metadata:

Scenario: Variation of basic scenario, Orientation – Hypothesis – Experimentation– Data Interpretation – Conclusion – Reflection

Students' prior knowledge and skills:

- No domain knowledge is required since this is the lesson.
- Basis ICT skills
- Basic inquiry and reflective skills in order to address the requirements of the activity

Organizational requirements:

- Computer lab (minimum 6 computers, one for each group)

Online Lab:

- Faulkes Telescopes[12] (Remote Lab), Galaxy crash[13] (Virtual Lab) [reference needed]

Orientation

Have a look at the following video:

- What are all these amazing structures you see? Are they all the same? Can you name some of them?
- Can you tell which of these are galaxies?

Notes for the teacher:

You may begin your lesson with a presentation of a video or numerous pictures depicting different galaxies. Trigger a small conversation with your class by asking your students the questions mentioned above and others like them.

Conceptualization

Sub-phase: Hypothesis

Step 1:

Let's see what we already know about galaxies!

1. What is a galaxy made of?
2. How many galaxies are there in the universe?
3. Do you know any types of galaxies?

[12] © Faulkes Telescope Project, official partner of Las Cumbres Observatory Global Telescope Network

[13] Scientific Development: Chris Mihos (CWRU), Greg Bothun (UOregon)
Java Programmers: Chris Mihos, Dave Caley (UOregon), Bob Vawter (CWRU)
Web Design: Cameron McBride (CWRU)

4. What is so special about the centre of galaxies? Why are galactic centres so bright?

Create a concept map: Write down all the concepts that you believe are connected to galaxies. Use arrows to interconnect the different concepts and explain how they are connected to each other.

Step 2:

Astronomers are able to catalogue galaxies according to their morphology due to the existence of certain classification systems. In order to investigate the origin of these morphologies astronomers use simulations. We will now put ourselves in the position of amateur astronomers. Our work includes two main tasks:

a) We will try to classify galaxies according to a classification system

b) We will study the process of their formation using simulations.

Let's try to set some research questions (hypotheses) which we will set out to investigate. Write down your hypotheses on the following questions which are related to the two tasks mentioned above.

a) What kinds of galaxies are there and how do we classify them? Do you know a classification system?

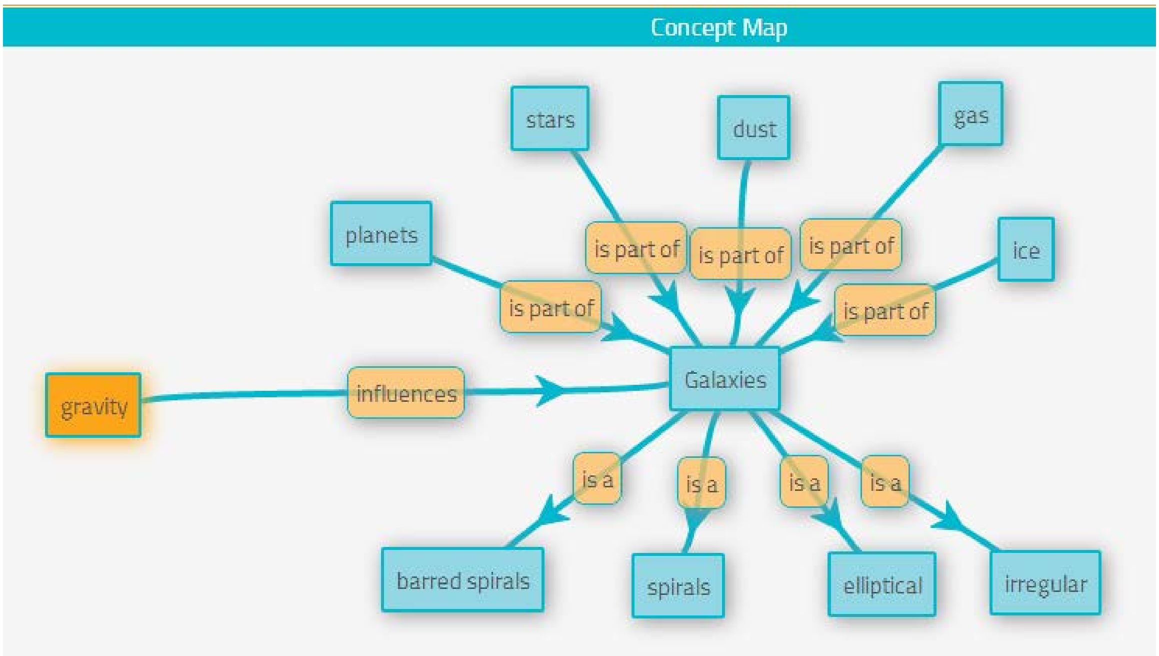
b) How are galaxies formed? How long does it take for a galaxy to be formulated?

Notes for the teacher:

Step 1:

During the discussion with students make sure to ask them some of the above questions in order to engage them further and check their background regarding the subject.

An example concept map could be the following:



Step 2:

You may inform your students about what they will do during this exercise:

- Learn how to classify galaxies

- Study images of galaxies which they will collect themselves using a robotic telescope

- Investigate the origin of the shape of the galaxy they'll observe using simulations.

Do not point out any mistakes students might make. Students are supposed to discover these mistakes themselves and correct them. Alternatively, you may note them down and bring them back to their attention at a later stage.

Investigation

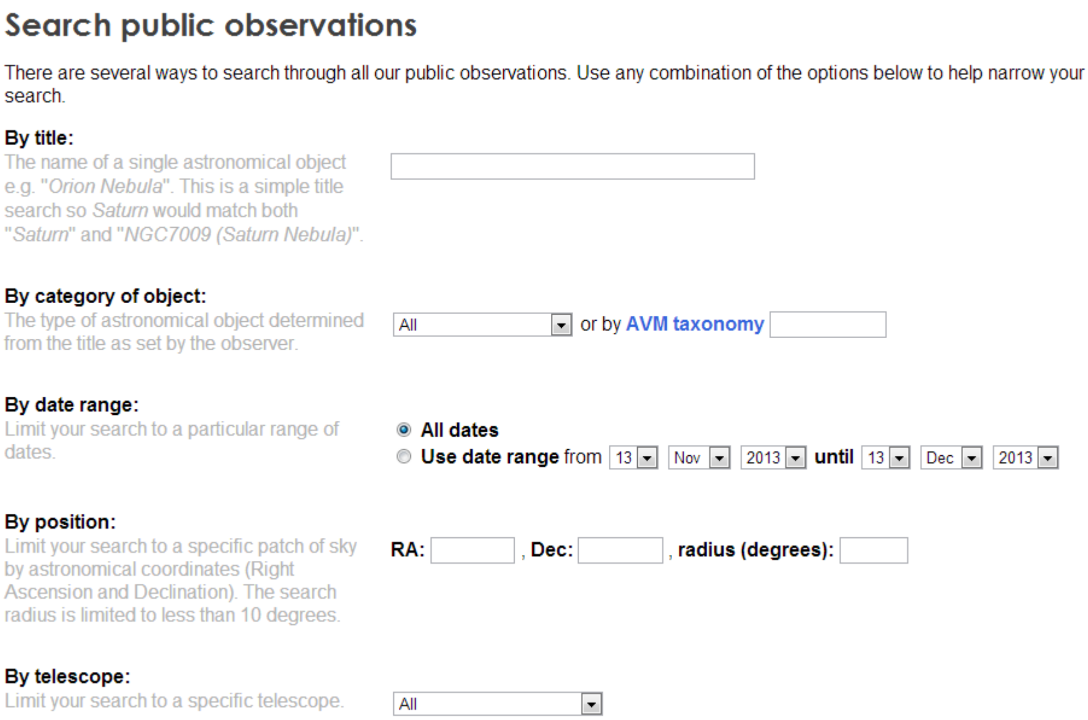
The investigation has two parts: “Galaxy classification” and “Galaxy Formation”. Students are divided into groups of four students. In each group, two students take responsibility for the “Galaxy classification” part and the other two for the “Galaxy Formation” part. Once the students finish their part they exchange their findings. Each pair of students checks and comments on the work done by the other pair.

Sub-phase: Experimentation

Galaxy Classification investigation

Step 1:

Visit the [Faulkes Telescopes data set]() and select 20 galaxy images and discuss about their morphology. Make a table of the galaxies and note down your observations about their morphology.



- Find which galaxies have similar shape and group them up.
- For each group of galaxies you created, now study the images more carefully and see if there are any morphological differences between the galaxies which could lead to subcategories.

Based on your observations and conclusions, design your own classification system. Categorize each galaxy of the list based on your classification system.

In order to present your classification you may either create a table or an actual drawing.

Describe briefly how your team came up with the classification system you created.

Step 2:

Search the internet and find how astronomers classify galaxies. Write a small text, comparing your galaxy classification system with the one you found during your query. Answering the following questions will help you write your report more efficiently.

- Are the two systems similar? What differences are there?
- What factors did you not take into account?
- Do you have any objections as to the system astronomers use?

Step 3:

Now you will try to classify galaxies based on Hubble's classification system. To do that, you will use the "Tuning fork Worksheet" file.

For each galaxy you selected in step 1, observe the image again closely and decide in which category you believe it belongs to.

Record the opinion of each team mate for the classification of each galaxy in the table you made in step 1.

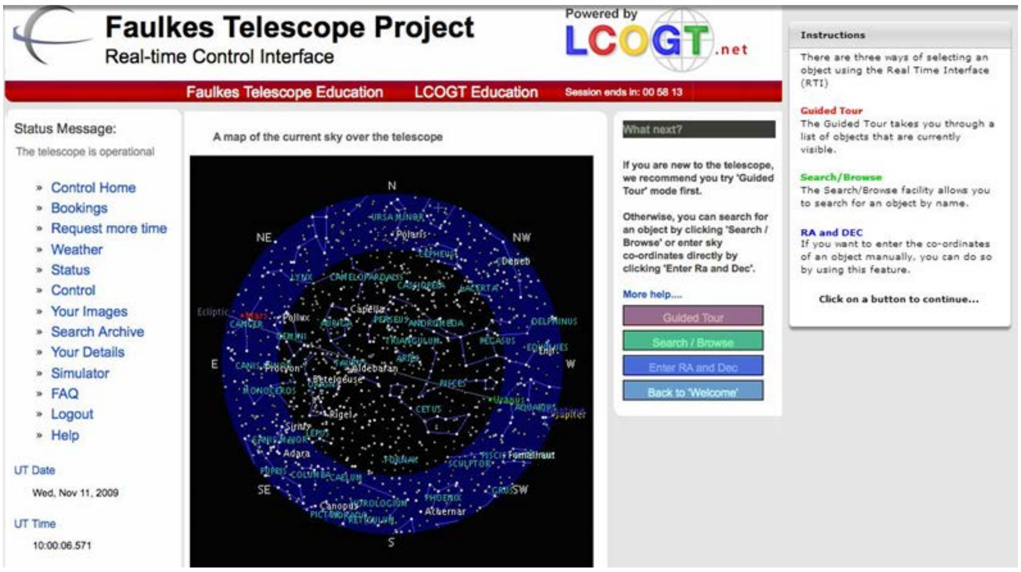
After concluding for each galaxy, write its name to the respective box of your "Tuning fork Worksheet" according to the final decision of the team.

Galaxy Formation investigation

Step 1:

In this part of our experimentation you are going to observe a pair interacting galaxies using a robotic telescope and you will investigate their origin.

You will use the Faulkes telescopes to observe a pair of interacting galaxies*. Choose one of two pairs of galaxies in the data table below to make your observation.



M51 and its companion, NGC 5195

Coordinates: 13:29:53.16, 47:11:48.120

Filter: Color

Exposure: 180 s

NGC 4038 - The Antennae

Coordinates: 12:01:52.68, -18:51:54.00

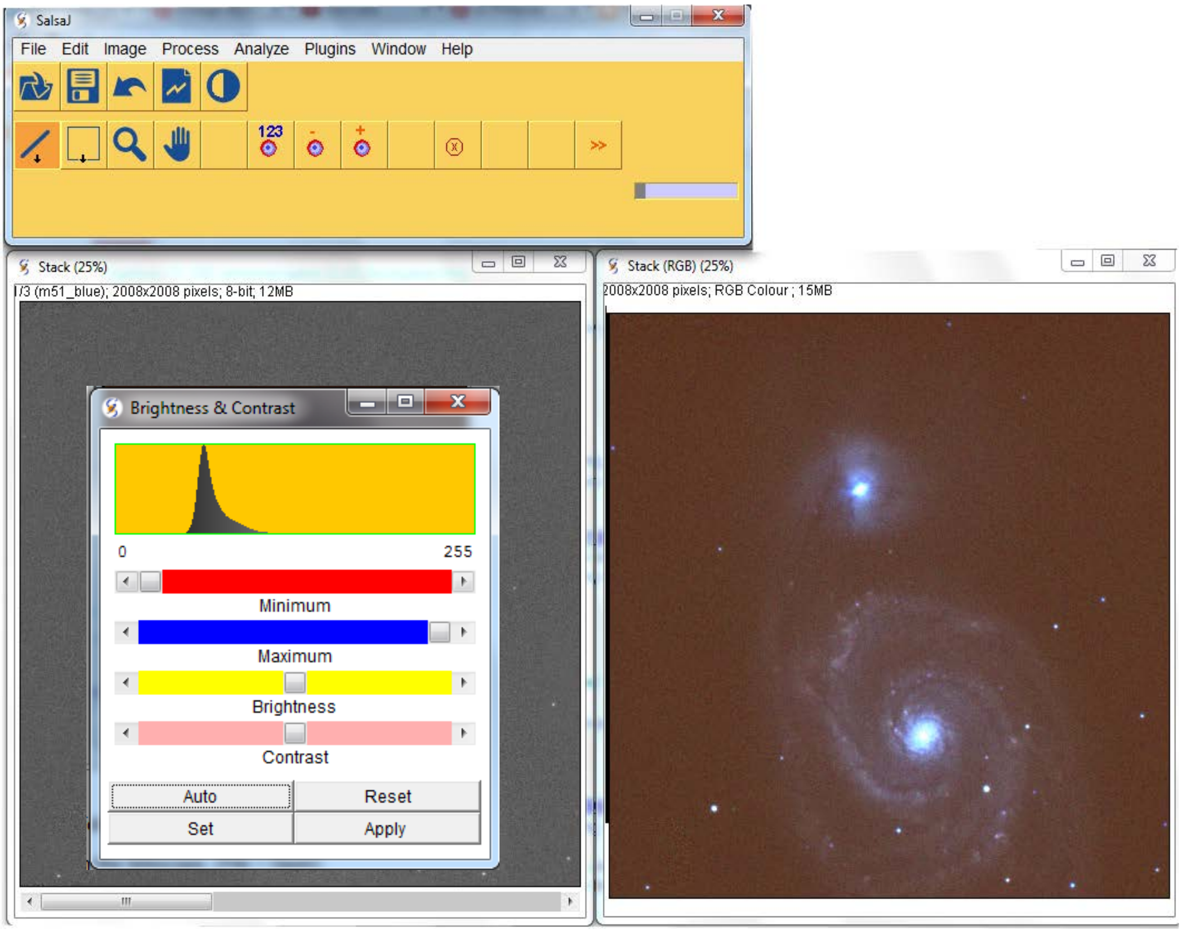
Filter: Color

Exposure: 180 s

Step 2:

Now use SalsaJ image processing tool in order to process the images you have collected from the telescope.

Using SalsaJ you can create a coloured image and adjust the brightness and the colours.



In order to create the coloured image, do the following.

a. Open the three image you captured with the telescope. (File – Open)
b. Create a stack of the images (Image – Stacks – Images to Stack)
c. Create the coloured image (Image – Colour – Convert Stack to RGB)

After you make the coloured image, click the “Brightness and Contrast” button (First button on the right of the top button menu)

Step 3

You can now use the "Galaxy Crash Applet" and try to recreate the image you captured with the Faulkes telescope and thus investigate the origin of the galaxy. Click on "Reset" and then "Start" to start the simulation. Use the panel on the left to adjust the variables of the interaction. You can change the angles of the two initial galaxies their distance and their relative mass.

Here are some indications that will help you get started:

- It is thought that NGC 5195 has a mass of about 30-50% the mass of M51.
- In recent simulations, astronomers varied the angle of inclination (theta) for M51 between 10-30 degrees, and for NGC 5195, between 25-50 degrees.

When the image on the "Galaxy Crash simulator" resembles the image you have captured with the Faulkes Telescopes use the "Print Screen" function of your computer to capture it. Then open the “Paint” tool and click on paste in order to see the image you captured.

Parameters of the simulation:

- Red/Green theta angle: Change the inclination of the galaxy.
- Red/Green phi angle: Rotate the plane of the galaxy that is perpendicular to the rotation axis.
- Peri [kpc]: separation distance in kiloparsec.
- Red galaxy mass: Set red galaxy mass in terms of green galaxy mass.
- Green Centered: Follow the green galaxy.
- Friction: Enable dynamical friction.
- Big Halos: Enlarge dark matter halos.
- You may rotate the image by clicking and dragging in view port.
- You may zoom by holding SHIFT and dragging.

Useful tips:

- It is thought that NGC 5195 has a mass of about 30-50% the mass of M51. In recent simulations of these two galaxies, astronomers - among other parameters - varied the angle of inclination (theta) for M51 between 10-30 degrees, and for NGC 5195, between 25-50 degrees.
- Astronomers believe NGC 4038 to be the result of a collision between two spiral galaxies of similar mass. In recent simulations of this galaxy interaction, astronomers incline both galaxies at 60 degrees to the orbital plane (i.e., theta = 60 degrees).
- Try not to change too many parameters at once in a run. See how each parameter individually affects the simulated galaxies first.
- Remember, we are only seeing the above observed interactions from one viewing angle, so click and drag the view of the simulation to see the interactions from different angles to see which best match our observations.
- The smaller the value for Peri, the stronger the tidal interaction between the two galaxies, but also, the faster the interaction, so long tidal tails may not form.
- The larger the value for Peri, the slower the interactions, but the weaker the tidal interaction between the galaxies, so again, long tidal tails may not form!

Step 4:

Once you capture the image open the “Paint” tool and click on paste in order to see the image you captured. Now use your drawing tool to process the image you have capture and compare it to the real image.

Notes for the teacher:

***It is better that all the students are engaged in the observation session with the robotic telescope, regardless their tasks. To this end, you may make the observations with the whole class or with every groups separately, before students start their investigation.

As the investigation may take quite some time, you may ask your students to complete the experimentation part at home.

Tip: Make sure students understand the connection between the investigation and the hypotheses they have made. In other words make sure they understand why they are doing every single step.

Students also have the tendency to change variables in an uncoordinated way. Guide them so as to make their investigation as systematic as possible by changing only one variable at a time and by keeping notes not only for their data but also about the process itself.

Check files “Relative theory”, “M51 and its companion”, “NGC 4038 - The Antennae” for the answer keys and the theory related to the classification of galaxies.

Sub-phase: Data interpretation

Based on the experiments you conducted, answer the following questions. Note down your answers in order to produce your report.

1. How good is the agreement for the classification of each galaxy? Are there some galaxies which are disagreed on more than others?
2. In which class does the galaxy you've observed belongs to? What comments do you have regarding the morphology of the galaxy?
3. Explain which parameters you used for your best model in the simulations you have carried out.
4. Based on your simulation, describe how the current shape of the galaxy has been formed.
5. Based on your simulation, what do you think will happen to these galaxies in the future?
6. What happens to the relative velocities of the galaxies as they reach their point of closest approach (perigalacticon, or peri for short)?

Notes for the teacher:

After the experimentation phase is finished ask the students within each group to exchange results so that all group members have a clear idea of the experimentation performed for both tasks. Have each group to perform the data interpretation sub-phase as a whole group and not in pairs.

Conclusion

In order to make effective conclusions try to answer the following questions based on your investigation. Note down your conclusions in your notepad.

1. How good is the agreement of your classification with Hubble's classification? Are there any galaxies (from those you studied) that you believe are not categorized correctly?
2. Would you make any suggestions to further improve Hubble's classification?
3. How good is the agreement of your simulation with the observed image?
4. Are there any parameters that you believe are missing from the simulation? Can you suggest any improvements?
5. How long did it take for this interaction to reach the observed stage?

Now look back to your original hypotheses and compare them to your conclusions. Do your results agree with your conclusions? Identify any mistakes you might have made while making your hypothesis.

Notes for the teacher:

You may mention the de Vaucouleurs system and ask your students to compare the two systems. (For more information regarding the two systems, see here.

If you have noted any mistakes that the students made during the previous phases make sure to bring them up and discuss them with their students so they may understand what their mistakes was.

Discussion

Sub-phase 1: Communication

Make a brief report of your work so you can present your work to your fellow-students. In order to attract their attention try to be as creative as possible. You can do a small video out of it, a

Prezi, a PowerPoint presentation or a poster like those presented by scientists during conferences.

Sub-phase 2: Reflection

Compare your results and the parameters that your team used in order to produce the images of the galaxies with those of other teams.

Are your parameters similar to those of other teams? Check if all teams have used more or less the same parameters, if not discuss about the different scenarios regarding the formation of the galaxies under investigation.

If you were to repeat the experimentation, is there something you would do differently? Why?

Notes for the teacher:

Comment on your students results. Point out which are the strong parts of their work and which are the weak ones.

Finally ask your students to comment on the accuracy of the method followed and whether the adaptation of such simulations can in fact produce valuable information for astronomers.