Science Teaching
Advanced Methods

Frameworks for Supporting Argumentation in Science Teaching and Learning
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This booklet brings together work conducted as part of the project called “Science Teaching Advanced Methods” with collaborations stemming from an earlier project entitled “Mind the Gap: Learning, Teaching and Research in Inquiry-Based Science Teaching” both funded by the European Union. The document begins with an overview of professional development activities conducted; and teaching and learning resources produced in France, Spain and England.

Subsequently exemplar ‘vignettes’ are presented on various aspects of teaching and learning of argumentation and communication in science classrooms. These include issues that have to do with curriculum, instructional approaches and learning environments. The intention is to provide a set of guidelines for what aspects of argumentation and communication are crucial for consideration in secondary science classrooms, and to give some examples on how to begin to implement such guidelines.

We acknowledge and thank the project teachers, pupils and schools for their useful contributions to the projects as well as the European Union for providing financial support. The partners from England, France and Spain have contributed equally to the writing of this resource.

The design of these resources was based on (1) epistemological analysis of physics modelling, learning and teaching hypotheses and on (2) analyses of classroom practice according to scales of time relative to teachers’ activity (Tiberghien et al. 2009). From research results, we consider that learning pathway follows neither a rational decomposition of disciplinary knowledge nor the order of introduction of taught knowledge in the classroom. The pathway towards understanding the relationships between concepts does not necessarily start by understanding each concept; the learner’s construction of his/her own understanding may involve simultaneously this relationship and each one of its terms. Another important aspect of learning is based on socio-constructionism, the classroom allows students to construct meaning on a social plane where the cultural development can take place. The students’ cultural development is favoured by the mediation of language and other people, particularly the teacher and other students.

The resources consist of six documents; each is associated to a specific classroom teaching component. The first one is related to global organisation and management of classroom (Document 1). Three documents deal with components that the teachers should have always in mind when teaching: making explicit the physics or chemistry modelling processes (Document 2); taking into account the students’ prior ideas (Document 3); taking into account the contexts of usage of physics terms (Document 4).

These components are not specific of a given moment of teaching (laboratory work, exercise, etc.). They treat of three aspects relative to students’ approach to take into account when preparing and teaching science. They are underlying almost all teaching activities, when preparing and during teaching, and in the same time they can appear, be observable during very short periods of time for example during explanations, answers to questions, etc. In this sense we consider that they fall under a macro scale that corresponds to an academic year or a whole teaching sequence of several months; they also fall under a micro scale, like the time of verbal interactions.

Two documents propose specific moment of teaching that are very relevant to develop argumentation: debate in whole class not as an organize debate but when students propose their solutions to the whole class then a debate can emerge between students on the teachers’ responsibility (Lyon document 5: Organizing debate and institutionalising), (Lyon document 6: Making students cooperate in small groups). These documents fall under a meso scale, that is the structure of a session into specific moments like recall, exercise, problem, experiment, discussion, debate. A session can also be structured according to the organisation of the classroom: whole class, group work, and individual work.

Each “document” has two parts. The first part is intended to be read by the teachers or teachers’ trainer directly and the second part proposed a deeper analysis which can be focused on a specific point. The first part is introduced by a short sentence supposed to be proposed by a student showing how physics teaching can be difficult for them. Then a text is given.
The resources are based on the activities of a continuing professional development (CPD) programme that was implemented as part of the “Mind the Gap: Bridging Policy, Research and Practice” project funded by the European Union. The programme was implemented in 2008-2009 with 6 secondary science teachers from 4 schools near Bristol, England in collaboration with researchers from University of Bristol.

Argumentation has been advocated in curriculum policies (e.g. DfES/QCA, 2006) and assessment frameworks (OECD, 2003) around the world. There is also now ample evidence that students increasingly visible through the “How Science Works” component of the national science curriculum (DfES/QCA, 2006).

Whist it was not possible to implement all features of this model (e.g. connection to other aspects of school change), our study shows that the following features contribute to fostering argumentation in science classrooms:

- immerse participants in inquiry, questioning and experimentation;
- be intensive and sustained;
- engage teachers in concrete teaching tasks and be based on teachers’ experiences with students;
- focus on subject-matter knowledge and deepen teachers’ content skills;
- be grounded in a common set of professional development standards and show teachers how to connect their work to specific standards;
- and be connected to other aspects of school change.

The purpose of the resources is to support communication and argumentation in the science classrooms, as a component of Inquiry-Based Science Teaching (IBST). Sometimes teachers may be already introducing argumentation and communication in their teaching, for instance, when they ask students to justify why do they give a particular answer to a question, why do they interpret a phenomenon as they do. Whenever teachers have goals as supporting students in constructing explanations and relating them to evidence, they have argumentation in mind. The goal of the resources is to support teachers in introducing argumentation in a more structured and explicit way. Argumentation, communication and the use of evidence are embedded in IBST.

The resources consist of four documents, each associated to a particular teaching component. Documents 1 and 2 relate to how teachers support particular students’ roles and practices; document 3 to the teachers’ role in inquiry and argumentative learning environments, and document 4 to the design of curriculum for promoting inquiry and argumentation.

Document 1, about how teachers support particular students’ roles and practices, focuses on inquiry and argumentation: helping students to design and carry out investigations.

Document 2, also about how teachers support particular students’ roles and practices, focuses on evidence: supporting students in identifying, understanding and using evidence.

Document 3, about the teachers’ roles in inquiry and argumentative learning environments: guiding and modeling scientific inquiry.

Document 4, about the design of curriculum for promoting inquiry and argumentation: designing curricula and resources that consist of authentic scientific inquiry.

The resources are intended to be read by the teachers or teachers’ educators directly, and the second part proposes a deeper analysis focusing on the use of evidence to support students, from classroom transcriptions in project RODA, carried out in the USC, in order to illustrate the topic discussed.

Some of the case studies used as examples in the guidelines relate to the booklet Resources for introducing argumentation and the use of evidence in science classrooms (Jiménez-Aleixandre, et al., 2009), also produced in the USC for the Mind the Gap project, and that can be downloaded from www.rodascu.eu.
Inquiry and argumentation:

Students should engage in processes of scientific inquiry:

- Communicate their work, explaining the study and results to an audience.
- Make predictions and suggest new questions emerging from the study.
- Prove claims on the basis of the available evidence.
- Consider alternative explanations for phenomena or results.
- Develop interpretations and explanations (theories) for given results.
- Question their results in order to find potential flaws.
- Interpret data; transform observations into other data formats.
- Make observations, collect, select and analyze data.
- Plan small studies, investigations and experiments to gather data.
- Design how to investigate them.
- Study research reports by other people.
- Design how to investigate them.
- Generate their own questions to be investigated.
- Construct justifications for their claims or use data to make a decision.

Engaging in scientific inquiry means participating in the processes of reasoning and knowledge construction that characterize science. Inquiry provides an appropriate environment for argumentation and the use of evidence, as students are required to select pieces of evidence, interpret them and relate them to claims. The best contexts for engaging in inquiry are investigative projects carried out during an extended period of time, rather than stand-alone tasks or activities.

How can teachers support this engagement in inquiry? How to provide students with opportunities to participate in authentic science? Or, in other words: What activities do students carry out when they are engaged in inquiry? Engaging in scientific inquiry means, for instance, that students:

- Generate their own questions to be investigated.
- Design how to investigate them.
- Study research reports by other people.
- Plan small studies, investigations and experiments to gather data.
- Make observations, collect, select and analyze data.
- Interpret data; transform observations into other data formats.
- Question their results in order to find potential flaws.
- Develop interpretations and explanations (theories) for given results.
- Consider alternative explanations for phenomena or results.
- Produce claims on the basis of the available evidence.
- Make predictions and suggest new questions emerging from the study.
- Communicate their work, explaining the study and results to an audience.

The interest and engagement of students with science and scientific phenomena is best achieved through opportunities for extended investigative work. Reports about how to improve science education point out that students should engage in processes of scientific inquiry.

Research studies suggest the need for students and teachers to participate in scientific practices. These practices relate to three processes associated to scientific knowledge: knowledge construction, knowledge evaluation, and knowledge communication. Challenges in the teaching of such approaches are acknowledged and practical suggestions are given through a classroom debate activity designed by a Bristol teacher.

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All these activities may be carried out, for instance, when students plan and implement an inquiry project, which is quite different from standard school experiments when in most cases students have little or no responsibility in the decisions, and follow instructions.

Participating in these practices needs a constant support and guide from the teacher, which is discussed in document 3. In other words, that students take an active role does not mean that they are able to engage in inquiry completely on their own.

To go further
Helping students to generate their own questions

From these activities, one, generating questions, is selected for a detailed discussion. The following examples are drawn from the work of the high school teacher Luis Fernández López (see Jiménez-Aleixandre et al., 2010, note 1). Luis Fernández requires, as part of the coursework in biology in the 9th grade (14-15 year old), that students plan and carry out an investigative project in small groups.

One unusual feature of these projects is that the students themselves need to determine the topic, to generate the question to be investigated. Even in classrooms where students engage in inquiry projects, they are usually provided with the questions. Deciding the questions has a number of advantages for teachers, for instance: they can design the projects to align with selected topics in the curriculum; equipment and resources can be prepared in advance; literature search can be conducted also in advance; the investigation can be rehearsed by the teacher, and potential difficulties identified. These and other benefits cannot be overlooked, and they help to explain why it is so unusual that teachers handle to students the responsibility for deciding upon the research questions.

However, there are also reasons supporting to assign this decision to students. First, that, as some authors propose, students should be given the opportunity to engage in the cognitive processes of conducting authentic inquiry, and these include generating their own questions, as scientists do. Second, to promote students’ ownership of the investigative projects, which is more likely to occur when they pursue their own questions, as compared with being provided with them. Third, to promote their interest and motivation in science, and in scientific practices, which as international comparative studies show, decrease as school years proceed. Fernández work provides some evidence about how this sustained strategy favours students enrolling in science options and even in scientific degrees.

Some instances of students-generated questions in the 9th grade (the last year when science is compulsory for all students in Spain) during the term 2007-2008 are reproduced below. The questions from the small groups were negotiated with the teacher, who provided suggestions. The projects took an average of six weeks to be completed, using about one third of the classroom time.

• How does physical exercise affects heart and respiratory frequency and blood pressure?
• Can we know the amount of annual rainfall by studying the rings in oak trees? Which was this amount in our town in the last decades?
• Does the moon cycle (moon phases) influence plant growth?
• Are moles hereditary?
• To which stimulus (voice, smell, sight) do dogs answer when their owner calls them?

The project about the influence of the moon on plant growth is discussed in detail in chapter 6 of the argumentation resource booklet (Jiménez-Aleixandre et al., 2009, see note 3).

Santiago: Document 2: Students’ Evidence

Students should generate, evaluate and use evidence and criteria for justifying scientific claims

Supporting students in identifying, understanding and using evidence

Presentation of this teaching component “We [chose] the first [Archaeopteryx, traits of both birds and dinosaurs] and second one [vestiges of hind limbs in whales], because they have a basis a bit scientific, as Tyrannosaurus. And the third [a book says that the increase in human height in the last years is evidence for evolution], at the end we finally decided that it was not [evidence], also for the same reason. Writing a book, ok, you can say whatever you want, but you need to demonstrate it.” (10th-grade student, Puig, Jiménez-Aleixandre, & Fernández, 2010. The context is a task about what do students consider as pieces of evidence for evolution).

Argumentation can be defined as the evaluation of knowledge claims. But, how are knowledge claims weighted? Scientists chose one explanation over others on the light of available evidence. But, this decision can be justified if evidence supports them or discarded if evidence contradicts them. In the cases when new evidence emerges, or when evidence is interpreted in a different way in the frame of new theoretical approaches, an old explanation may be substituted by a new one. Evidence plays an important role in the construction of scientific knowledge, in particular in these processes of evaluation.

The use of scientific evidence by students is one of the three dimensions in the scientific competence, according to the framework of the PISA international evaluation, and to the recommendation of the European Union in 2006 of a set of core competences for lifelong learning. These three interconnected dimensions highlighted in the PISA framework are:

- Identify scientific issues and questions that could lend themselves to answers based on scientific evidence.
- Explain or predict phenomena by applying the appropriate knowledge of science.
- Use scientific evidence to draw and communicate conclusions, and to identify the assumptions, evidence and reasoning behind conclusions.

The implication is that, in learning environments that promote argumentation and inquiry, students should generate, evaluate and use evidence and criteria for supporting scientific claims. However, despite this emphasis on curriculum documents in many European countries, and in the PISA framework, teachers need support for translating these policy orientations to the classroom, for designing classroom environments taking into account these recommendations, for implementing learning tasks that promote the development of the capacity to use evidence to evaluate knowledge.

Research studies on argumentation have explored the use of evidence by students, reporting difficulties as the differences between the criteria used by students and experts; to what extent students use the available evidence or ignore it; how they are often unable to cite sufficient evidence for claims; or the difficulties they experience for explaining how given evidence provide support for claims.

Which practices do we have in mind when talking about students’ use of evidence? Students are engaged in using evidence in classrooms where this is required from them. However, it is more likely to occur in inquiry-based science classrooms, when they are involved in investigative projects.

In lecture-based instruction students are not usually required to appeal to evidence. In
inquiry and argumentative classroom environments, students are required, among others to engage in:

- Developing and using criteria about what constitutes appropriate evidence and what does not. For instance, some criteria are: specificity, reliability.
- Distinguishing between data that may be used as evidence and mere opinion.
- Selecting information from different sources and evaluating its reliability.
- Selecting data, empirical or hypothetical, appropriate for supporting given claims.
- Backing their claims or choices with evidence.
- Examining experimental evidence in the light of previous predictions.
- Generating evidence through investigative projects, in order to answer research questions.
- Evaluating the available evidence and its connection with the claim that is being tested.
- Drawing on their knowledge in order to generate justifications that connect evidence with claim.
- Articulating evidence-based reasoning lines for supporting a claim.
- Criticizing claims by others, on the basis of evidence.

As with other competences, the use of evidence needs to be practised under the continuous guidance of the teacher.

To go further

Supporting students in developing criteria about what constitutes evidence and how to generate it

From these dimensions in the use of evidence, one, developing a notion of what evidence is and how can students generate it, is selected for a detailed discussion.

The following example is drawn from the doctoral dissertation of Ramón López Rodríguez (2001, see note 4); see also Jiménez-Aleixandre & López Rodríguez (2001). The context is a 4th grade (9 to 10 year old) classroom preparing a field trip in order to study a pond. The teacher, following the methodology and constructivist approach used in the school, assigns students the responsibility of decisions about how to behave outdoors (sessions 1 and 2), what to study in the pond (sessions 3 and 4) and how to study it (session 5). All the names are pseudonyms.

In session 3 the students, working in small groups, have prepared proposals about what they are interested in studying. The transcription reproduces a fragment of the classroom debate when the groups are presenting the proposals and trying to reach a consensus.

Teacher: What else are you interested to know about the pond?
Nestor: The food chain... we have to...
Fina: We want to know what do the pond animals eat.
Teacher: Come on, Fina, explain it well, go ahead.
Fina: We want to know what do the pond animals eat! Do you see? And how do they eat one another and who eats whom.
Teacher: And how are you going to study that?
Lino: First we will look in the books and then we will observe...
Fina: ... whether it is true.
Lino: We will observe whether it is true, or maybe they [the books] are wrong... Perhaps the book is telling about just one pond and not all the ponds in the world. Then we need to look and see what is there.

In this excerpt it can be observed, first how students draw from their previous knowledge in order to make proposals: Nestor refers to “the food chain”, an abstract category, which reveals a higher level of cognitive performance than the mere mention of instances of the category as “what do frogs eat”. Scientific literacy and argumentation are intertwined. In her second turn, Fina shows that she is attempting the meaning of “food chain”, clarifying it.

The teacher, in her third turn, “how are you going to study that?” supports the students in developing ideas about how to generate evidence about the food chain in the pond. Rather than giving students a set of instructions about how to study the food chain, or how to collect data, she shares with them the responsibility for learning. The teacher promotes her students talking, science, and her utterances, as the four examples reproduced above, encourage students to develop their proposals, to clarify them, to unpack their meanings, in summary, assigning them an active role.

Another feature of the classroom that can be observed in the excerpt is the 4th grade students’ ideas about what constitutes evidence. Lino and Tina’s utterances may be interpreted as an indication of the status of empirical evidence, and of their own observations in the field. They do not accept books’ authority without questioning, considering themselves knowledge producers. This is an example of students taking an active role, which is supported by the teacher’s style and strategies. Of course these methodologies are more time consuming that just giving students instructions. The teaching sequence took ten days, five of them spent in the process of decision-making. We think that it can be said that this time was well employed, in terms of the students’ development of competences.

Bristol: 

Communication and Persuasion

Students should be able to communicate scientific ideas in various ways including writing, debating and using symbolic representations.

Supporting students in sharing scientific ideas through writing and talking in various ways

“...The language behind it [scientific idea] is really really difficult for them to get their heads around. [For example] they don’t know how to pose a question scientifically. They found it is really really hard.”

“We need to find a way… to scaffold them to pose questions… of them being familiar with what the question set-up would look like.”

Asking questions is at the heart of communication in the classroom. Questioning enables students to not only consolidate their learning but also to model scientific modes of thinking. Communication of scientific ideas is an important aspect of scientific inquiry and scientific literacy. Educators and researchers have argued that communication and representations can help students to further develop their understanding of scientific ideas.

Communication and representation offers the opportunity to make students’ thinking visible and explicit. Moreover, in technologically rich societies where information gets represented and communicated in a range of formats, students should be able to communicate in varies ways, including drawing conclusion from evidence presented in the media. Many teachers engage students in a range of activities to help students improve their communication skills. For instance some teachers ask students to design posters, use concept maps to represent their scientific knowledge and debate opinions of scientific ideas with peers. However, communication and persuasion are not easy skills for students to acquire. As the quotes by some Bristol
teachers illustrate, students can face problems in expressing scientific language including scientific questioning.

What counts as meaningful communication and representation of scientific ideas? Some researchers (e.g. Erduran & Jimenez-Aleixandre, 2008) have argued that students need to be taught explicitly how to communicate scientific ideas. The Bristol teachers have found their students got problem of communicating scientific ideas. For example, the students don’t know how to write a sound scientific argument or how to draw conclusions based on collected data. Foremost, students need to know what the criteria for effective communications are (i.e. what should be the feature of a productive group discussion?) before they can engage in the activities and achieve learning targets through such activities. For example, students need to know the principle of evidence-based argument and the structure of the scientific argument before doing debates about scientific ideas. It is difficult to imagine that students will have sound communication of an argument if they do not know or understand the nature of an argument. The students should also be aware of different means of communication and be able to choose the proper ways to exchange or represent their understanding of scientific ideas. For example, verbal presentation may not always be the best strategy to illustrate complexity in data and how such data would amount to a particular interpretation. Students should gain some appreciation of different means of communication, their strengths and weaknesses and how to map the appropriate communication strategy for the purpose at hand.

We often think students are not good at asking questions but I felt it was actually upside down. If you get some interesting thing happen, the questions will just come up naturally. So we need to find some resources that bear the questions. It could be different to different people.

Likewise anticipating the range of target audiences of scientific information would be a useful skills for students to acquire, because afterall, science has many faces engaging a range of stakeholders from policy-makers to the practising scientists.

Engaging pupils in argumentation is important because it places the students in the position where they can begin to collect, interpret and evaluate evidence for our claims. In this respect, science learning becomes aligned with how scientists themselves “do” science. Science is not about cookbooks where procedures are replicated mindlessly. Manipulation of variables for the sake of verifying already known outcomes is also not scientific in nature. Authentic scientific enquiries would allow for the generation of evidence and justification of scientific knowledge in the classroom. They would create room for pupils not only to generate and evaluate evidence but also to establish the criteria and standards by which to judge evidence in the social environment of the classroom. Authentic scientific enquiries would have argument at their core (Erduran, 2007).

Another reason for why argumentation is important for science education is that recent accounts from educational psychology has demonstrated the important role of talk and language in learning. Language contains the linguistic structures and patterns that define and shape an endeavour like science. Language has a lot to do with thinking as well. Indeed some psychologists like Lev Vygotsky have claimed that thinking itself is shaped and formed by language. When we turn to talk and language of science classrooms, however, we witness that the predominant form of talk is what is typically called the IRE sequence: Initiation, where the teacher asks a question; Response, where the student gives an answer; and Evaluation where the teacher evaluates the students’ response and then typically moves on to another theme. Although useful for certain purposes, this type of verbal interactions in the science classroom does not promote extended discussions where pupils’ ideas can be projected to the public domain and where the teacher or other pupils can negotiate and resolve ideas. Strategies such as group discussions do help in breaking away from the constraints of IRE patterns and getting pupils engaged in more varied interactions in talk. Without a chance for pupils to talk to each other, without the space to debate and communicate their ideas, it is difficult to imagine how pupils could consolidate their learning.

To go further
A class example: Producing posters to communicate ideas on magnetism (Erduran, Polat & Raveaud, 2008)

Class background: Year 8 group.
Class activity: Proposing models of how magnetism plays a role in loud speakers.
Class aims: (a) To get students to experience the process of communication and representation, (b) to select information and knowledge from the internet, (c) to choose the proper text and graph in order to present their ideas to each other with posters.

The Year 8 group was a small special educational needs group in which two students in particular were considered to be in need of extra attention. The teacher provided descriptions of the two pupils’ behaviour and motivation. One of the students was described as “lazy, zoning out for the lesson, lacking motivation, actively not working, doing no homework and not responding to positive praise”. Although the second target pupil was described as highly motivated he lacked skills in “time management, handwriting, working on his own, and was excluded from other student groups”. The activity described below was chosen to encourage group involvement in that it was based on the following factors: “no
Global organisation and management of classroom

Lyon: Document 1

Presentation of this teaching component

In class I always feel that the teacher puts on a show, everything comes from the teacher even when he asks questions, I just have to take notes on what to know, and so the next day I do not remember anything.9

Current theories of learning give an important role to students in the construction of knowledge. The student is regarded as an architect of his knowledge. According to these theories, students by acting on the material world and organizing it; this organization is greatly enhanced by interactions with others (see Lyon documents 5 and 6 on debates and cooperation). This implies a certain functioning of the class in order to make students active and favour their involvement in the learning process.

One of the choices we make in order to involve students in constructing knowledge is to build a teaching based on activities, projects etc. The establishment in the class of this functioning causes a gradual but long change in the relationship between the teacher and his/her students. The teacher rating on the material world and organizing it; this organization is greatly enhanced by interactions with others (see Lyon documents 5 and 6 on debates and cooperation). This implies a certain functioning of the class in order to make students active and favour their involvement in the learning process.

All this leads to a contract between teacher and students that should be made explicit and should be justified as much as possible. It is necessary that students understand and adopt the stakes in the activity and be able to work in small groups sharing the same issue.

In order for this functioning to be effective, considerable work of preparation and choice of activities or projects and instructions given must be done by the teacher. It is not simply about introducing or illustrating a teaching based on lectures by activities of discovery or reflection as the ones we sometimes find in textbooks. The student should often be guided by detailed and well structured activities, which will allow him not only to elaborate his own ideas but also to express them freely and thus contribute to the advancement of knowledge in the classroom.

To initiate the discussion during an activity, it seems essential to prepare the way the situation and its stakes will be presented. The goal of this presentation is not allowing students to give the right answer, but helping them understand the issue or problem proposed. One objective of these stakes is to motivate students so that they engage in the task aiming at building new ideas. For example we can ask students to make a prediction or hypothesis by taking a clear position. Their involvement is easier to get when they know that the answer will be given "by the experiment" and not by the teacher himself thereby reducing the sense of arbitrariness.

The use of experimental situations in activities is very important to engage students in building their understanding of science. These situations can be elementary situations involving simple equipment, some may be proposed by students in order to verify certain hypothesis. It is also interesting to introduce situations of everyday life or social questions where science is involved.

If the goal of the whole activity is the construction of complex knowledge, each item of the activity must be accessible to students. Each student should be able to provide answers to questions whether or not they are correct.

To go further

The teaching method that we propose introduces a variety of task-based activities which follow the general curriculum. These activities can vary in length and nature and may require individual interpretation and/or need for laboratory experiments. Therefore this presentation focuses more on the teaching method and the instructions given to students in class, rather than on the type of activity proposed.

Working in small groups:

• Encourages student autonomy when learning new topics. Teachers can assist individual groups where necessary
• Provides the students with a first understanding of new topics through discussion, experimentation and reading

Sharing the results with the whole class:

• Encourages students to present and defend their findings to the rest of the class
• Enables teachers to correct any of the findings and sum up the new knowledge covered

The activities thus structure the teaching method.

During these activities the teacher allows enough time for students to work autonomously in small groups (or in pairs). If necessary, the teacher can assist individual groups, especially if they have not clearly understood the instructions to be carried out. This choice of teaching method leads teachers to hold debates with the whole class and allows them to present the ‘Physics’ view point on a situation which has already been analyzed and shared by all.

This active teaching method is clearly a move away from the traditional juxtaposition of classroom based activities and practical experiments. From the students’ viewpoint these practical experiments are no longer seen as a sideline to classroom based teaching (e.g. verification of results given in class or introductory experiment on a new subject) but instead as a fully-integrated part. It is preferable that lab-based experiments be conducted in half-class session. Our teaching material has thus been put together to alternate lab sessions with class work. Class work and corrections should be covered during the larger group sessions.

It is important that the teacher presents this method to his/her students at the beginning of the academic year in order to have their buy-in. The teacher should also remind them of this regularly during the first lessons. This teaching method is one of many, and it may be poorly adapted in certain cases if the curriculum is dense. It may thus be necessary to alternate this method with lectures. However we believe that practical experimentation furthers student understanding. A teacher wishing to use this method could start by implementing it on part of a course (e.g. Mechanics with 15-16-year-olds), keeping in mind that this changeover may pose some problems for students in organizing their work.

Progressively implementing this teaching method brings about a slow change in relationship between teacher and student. Choosing activity-based teaching assumes greater implication from the students. The student is not left to his/her own deives, but rather guided by detailed and structured activities. It is not simply a matter of introducing or illustrating a traditional lecture-based teaching by discovery or follow-up activities as can be seen in many textbooks. For this method to work, both teacher and student have
to be in agreement. This type of ‘contract’ has to be explained and justified as far as possible. Students need to understand the importance of these activities so that they can work together in small groups with the same interests.

It is not uncommon to experience a period of instability whilst implementing this type of teaching method. Some questions will appear spontaneously: When should I end group discussions? When should I give corrections? Persevering despite setbacks often pays off (both for teacher and student). Given the increased time needed to manage a class in this way, it may be easier to implement with 15-year-olds than with students in their final exam year. In order to cover the curriculum in its entirety, it will be necessary to reduce the time spent on study and debate at certain points of the official curriculum. It is unrealistic to imagine that this time-consuming method is adapted to all levels of teaching.

Santiago:
Document 3: Teachers – Guiding and modelling scientific inquiry

Presentation of this teaching component

“I also believe that it is important to study the origin of the water in the pond, and besides it is something that we all could investigate. Zoilo: Well, I however do not think that it is so important for us all to be dedicated to it. And besides, if a group is doing it, once they discover it, once they know about the origin of the water in the pond, they can tell it to the rest of us: Can’t they?”

Hugo: Yes, of course they can, but it is not the same to discover it by yourself that being told.”

(4th Grade students, discussing about how to study the pond; López Rodríguez, 2001; see notes 4 and 6)

Inquiry-based science teaching and learning, as all learning environments framed in the constructivist perspective, places the student at the centre of instruction, assigning her or him an active role. However, this does not mean that in these classrooms the teacher has the same role as the students. It is the teacher who directs the research and steers the learning goals. Learning is contemplated as a process of social participation in a community of practice, participation that requires modelling and coaching. The teacher provides scaffolding for the students’ performances, favouring that they progressively assume the responsibility for learning.

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Inquiry-based learning contexts provide appropriate environments for argumentation to take place, for inquiry and argumentation goals are complementary. In these contexts the teachers take on roles as for instance to model and guide inquiry. That means that students witness teachers:

• Learning and discovering.
• Doing research.
• Planning how to investigate scientific questions.
• Selecting, analyzing and interpreting data.
• Coordinating claims with evidence.
• Reading and writing science.

All these practices conform a very different role from emphasizing lectures or classroom management. In particular, in order to promote argumentation, teachers should encourage students to provide evidence to justify their positions, challenge their ideas pointing out its limitations, and provide criteria for the construction of arguments and for the use of appropriate evidence.

Research reports suggest that, among the critical strategies for developing inquiry, teachers pay attention, for instance to calling the students for clarification, evidence and evaluation.

• Clarification, asking students to revise their answers: Could you say it in other words? How else might you say that? Can you explain it to make it more understandable?
• Evidence: Why do you think that? How do we know it? What do you think your data show?
• Evaluation: What other causes might have produced that? How could we do this study in a different way?

Some instances of a teacher using these strategies to elicit clarification are discussed in document 2.

We need to take into account that there are different forms of inquiry, sometimes described as a continuum, from more structured to more open. In structured inquiry students are provided with the questions and procedures, and they generate evidence and build explanations, while in open inquiry students are in charge of all the process, beginning with the questions asked. Guided inquiry is somewhat in the middle, with students being provided the questions, but designing the procedure.

To go further

Guiding students in developing investigative projects

From these dimensions in guiding and modelling inquiry, one, the guidance of
students in developing investigative projects, is selected for a detailed discussion. The following examples are drawn from the work of the teacher Luís Fernández López (see Jiménez-Alexandre et al., 2010, note 1) and his 9th grade students. In Santiago document 1 this work was discussed from the perspective of the practices required from the students, and here the emphasis is on how the teacher guides and supports the planning and development of students’ investigative projects in small groups. Fernández has been working with this approach during ten years, although this document focuses on the projects of the term 2007-2008.

When introducing innovations, teachers worry about how do they fit with the curriculum. For that reason, thinking about how his strategies may be transferred to other classrooms, Fernández planned the biology and geology course schedule so that the whole program was covered. On average, from a 25% to a 30% of the time in each teaching session was dedicated to work about the projects, and the remaining time to the development of teaching sequences on the program’s topics.

In order to introduce students progressively to participation in the projects, the teacher established three stages:

• Stage 1 – Students are introduced to investigative projects and experimental work; includes for instance, teacher introduction; case-analysis of research projects and students’ identification of research questions, methodological approaches, the meaning of dependent and independent variables; or the notion of evidence and evidence-based claims. Also, in cooperation with the mathematics department students were introduced to basic statistics notions.
• Stage 2 – Students engage in guided inquiry and formulate their research questions and initial design proposal; during this stage the students carried out simple projects about questions suggested by the teacher, in other words, they were engaged in guided inquiry. They also proposed research questions and wrote initial design proposals, guided by the teacher, as discussed below.
• Stage 3 – Students carry out their investigative projects and communicate the results; students developed their projects in small groups, wrote their reports and communicated their results to the classroom, school and wider community of families and neighbours. The projects took on average six weeks to be completed.

The implication is not that this is the only way to support students’ engagement in inquiry, but that it is a way coherent with the perspective of cognitive apprenticeship, and social participation in a community of practice, progressing from the periphery to the centre under the guidance of the expert. They begin by studying and analyzing research cases, then proceed through guided inquiry, to open inquiry.

How is the teacher’s support provided in stage 2?

• First, by suggesting the questions, which provide models that could be used by students when formulating their own questions.
• Second, by revising, both privately through email and publicly in the classroom, the research questions formulated by the students.
• Third by introducing students to the structure of research proposals (research questions / objectives; methods; equipment needed; research plan and budget up to 60 euro). Once the students write a first draft of the proposals, they are revised by the teacher, who suggests how can be improved in order to be viable.
• Fourth, by evaluating the design proposals; then the high school provided financial support to those approved. Some research questions and proposals were submitted to a national contest of students’ research projects organized by the Science Museum, which retains some and funds them.

Again, this is one among different strategies for supporting students’ participation in investigative projects. There are other possibilities, although this one is coherent with scientific practices, and one which emphasizes the discursive and cognitive practices that make part of the scientific work, the iterative nature of processes that have as a goal to improve plans and proposals, the quality standards to be met in order to achieve funding. In other words, it conveys an image of complex practices and not just of hands-on experiences.

In summary, Luís Fernández work provides a good model about how to support students’ engagement in inquiry. The emphasis on communication in the third stage is aligned with the relevance of the communication processes in the construction of scientific knowledge.
Helping the students by making explicit the functioning of physics and in particular modelling

Lyon: Document 2

Presentation of this teaching component

“When the teacher asked me to explain why the boat does not sink and I said because the water prevented it, he told me that I had understood nothing about the question! Anyway I never understand what we have to do in physics…”

Very often, students perceive the activity led in physics as puzzling or arbitrary; this can partially be explained by the fact that they have a difficulty in perceiving the objectives of physics and the way it works. For that purpose, it is advisable to allow the students an understanding of the way physics works, in particular from the point of view of modeling.

We suggest making as much as possible these relations explicit for the students, because they are often difficult and puzzling for them but facilitate nevertheless the understanding of physics and what physics is: by making these relations the students can give meaning to the model to be learnt. For this, the teacher should:

- analyze finely, during the preparation of a session, what belongs to each of both “worlds” (left figure). This analysis contributes to appreciate the complexity of what is asked to the student and can avoid putting him in front of an insuperable task that will confuse him.
- take into account this analysis as well when writing the documents given to the students as in the oral speech: the teacher avoids the confusions between objects-events and theories-model, which allows him/her to make explicit the relations between realized observations and elements of the taught model (concepts, statements, etc.).

In longer term, this allows the justification of the choice of the experimental situation under study. Often, this justification can take place only a posteriori. It is in particular the case for assemblies which hide elements that are not relevant for the model in order to spare time and avoid trial and error (air cushion table, half-cylinder of Plexiglas for the law of Descartes).

Finally, this allows the teacher to justify the choice of the model used to describe or interpret the situation. For example, a model of electrokinetics is of no help to interpret the battery wearing off, while an energy model will be relevant.

To go further

Understanding how physics and modelling in particular work

Justification and detailing choices made

Do not confuse students

- Show how physics and chemistry function with modelling

We are trying to avoid teaching physics and chemistry in a way which overly confuses students. For that purpose one of our major proposals is to allow students to get an idea of how physics and chemistry work, in particular as far as modelling is concerned. We make clear where possible, that the physicist or chemist’s main activity is to connect objects and events with models, these models remaining valid until invalidated by a new situation (for example, simple gravity pendulum, Lewis model, thin-lens model). We also have to explain the inevitable choices that the physicist or chemist must make as soon as they describe a situation, according to the goal of the study and models used.

The essential activity of the physicist is to put in relation objects and events with theories and models. To build and test a model allows the refinement of a theory, its validation or its use when it has already been validated (as it is often the case during teaching). These relations are made, including in teaching, in both directions: for example to induce an element of model from observations or to use a model to interpret or predict an event.

If the activity of the students is not absolutely traced on that of the physicist, we think however essential to give the students some marks that allow them to situate their activity with regard to the theory or the model: to search for a new theoretical element, to use a model to predict, test the validity of a model, to investigate the field of validity of a model, to build a specific model of a situation… These activities are essential in an inquiry approach.

We believe that the student can often not interpret the result of an experiment by referring to a model as this requires a difficult construction of links between the material situation and the model. These links are however at the crux of learning. It is only by confronting them that the student will be able to give the model the expected meaning, that is to say the meaning used in physics or chemistry. Moreover, he will be able to see the application and utility of the same model in apparently very different material situations.

The switch from experiment to model does not pose any problem for the teacher, who doesn’t need to break down the often complex steps required of the student when switching between experiment situation and model. Their knowledge and experience sometimes prevent teachers from being aware of the process and evaluating the difficulty this represents for students. This analysis will help us appreciate the complexity of what is required of the students and avoid giving them an impossible task to accomplish which will put them off.

This requires the designers or teachers to temporarily set aside their knowledge and put themselves in the student’s shoes as much as they can.

Consequences for the design and analysis of activities

Give the students clues to help them understand if you are asking for something experiment- or model-related or connections between the two

State at which level interpretations, predictions, explanations and justifications etc are to be made, being careful in your choice of terminology

When designing activities, we must remember the need to give students clues as to whether we are asking for experiment-related or...
theory/model-related ideas or the connection between experiment and theory/models.

Students will spontaneously stay within the bounds of what they have just been working on, or choose that which is more familiar, or that which they think is expected by the teacher. This register is often the realm of objects, events or if necessary, experiment. To obtain the expected attitude, instructions must have sufficiently clear clues. This need to supply signposts in what is asked of the student poses several big problems when designing ‘open’ activities, particularly for the first few that the students do during their studies.

To be able to make sense of words like justify, interpret, predict, explain students must understand what part a material situation on the one hand and on the other hand elements which allow its analysis (concepts, laws, principles...) play. In this way, justifications required of the students during activities, practicals, exercises or tests often confuse them as they don’t see what type of justification is wanted. It may refer to an experiment or exclusively to a model. The expected justification sometimes requires you to correlate elements of the model and of the experimental field, a particularly difficult exercise for students. On the contrary, the teacher expects a very precise answer and does not always realise that he or she made an implicit choice and that a student’s imagination can be very fertile.

This need for rigour in the choice of words and turns of phrase is all the more important as, too often, documents that a student has to read have not been written with this in mind. This rigour should not stop us from using when possible terms which both describe a situation and model it (for example the terms action, speed, vibration...). The student must gradually learn to distinguish observable objects and events from theories and models.

Explain the model in written form clearly identified as such

To help the student gradually learn to distinguish what happens at the level of objects and observable events and the way to interpret these using theories and models, it may be useful to supply whenever possible a written form of the model (made by the teacher or taken from another source). The fact that the model is given in written form helps the student to distinguish between model and experiment (or more generally between model and material situations). The students therefore have before them on the one hand the very real experimental situation and on the other hand the model clearly stated in the document.

This written model supplies the scientific terms and helps the student to distinguish the meaning these words have in physics or chemistry and in everyday language, or to become aware of nuance in the usage of these terms (see 2nd cornerstone). It is an essential part of what the student must use in the long term.

The text of the model repeats the formal statements of institutional physics and chemistry theories (laws of mechanics, law of conservation of energy, Lewis structure...) but is presented, formulated or completed so the student will understand it.

Modeling activities are almost systematically accompanied by a symbolic representation which also implies making choices. More about dealing with this aspect of analysis design...

The type of representation involved in modelling can go from a diagram with captions similar to what the student has under his/her eyes to much richer symbolic representations which include elements of the model, as used when representing a chemical cell or an optical apparatus, but much further away from the material situation. Each representation will highlight one or more aspects of the model (or described situation) and this choice is never insignificant. So changes made to these representations, if explained, help raise the student’s awareness of modelling processes.

Consequences for the teacher’s attitude in class

Teachers will often spontaneously refer to the model because it provides them with clear criteria as to whether students’ answers are relevant or not. They refer to it all the more readily as they perfectly master the meaning of the model and how it relates to objects and events. It is in the teacher’s best interests to avoid any confusion between facts and theories/models when speaking or in written documents (written model, activities, practical sheets, exercises, tests etc). So when the teacher establishes a link between observations made during an experiment and elements of the model (concepts, quantities, statements, etc), they had better be clear. This is in fact an act of modelling which is almost never easy for the student. These relationships will not be seen by the student unless the teacher uses different terms to describe the experiment and to interpret it in physics and chemistry model terms.

It is particularly important for the teacher to be vigilant in their speech while the ideas in question are not yet absorbed by the student. As soon as he/she feels it necessary, the teacher can ask students to refer to the written model when in a discussion it appears necessary to come back to what physics or chemistry has to say about the situation being studied. Asking students to refer to the written model helps them to gradually distinguish what happens at the level of objects and observable events so they can interpret these using theories and models.

The student is not often involved in the choice of experiment (equipment, procedure) and questions which go with it, as it is dictated by needs which are unknown to him/her (by the underlying model, costs or organizational questions). The student may be confused if the teacher does not take the time to explain why the device was designed this way or if the relevance of carrying out the experiment in this way is not demonstrated. This will be the case particularly for manufacturers’ ‘turnkey’ apparatus, which highlight valid elements for the model not yet encountered by the student and gloss over the rest to save time and avoid trial and error. If used, this equipment designed to correspond exactly to the model (wave machine, air table, semicircular Perspex block for Snell’s law of refraction...) must be presented to the students as an integral part of the modelling procedure. More generally, explaining and justifying choices underlying an experiment and its modelling help not to confuse the student who would probably have made different choices. This explanation can only take place after the experiment in many cases.

This vigilance as far as modelling is concerned can also lead the teacher to explain the reasons why any given situation is modelled in such or such a way and explain what can be gained or lost by proceeding in this manner. For certain situations it is possible to show that the question points to the choice of relevant model, but that this model choice is only really possible when you know all the different models available. For example, an current-based model will be of no help in interpreting battery wear, while an energy model will in this case be relevant.
Building your teaching by taking students prior ideas into account

Lyon: Document 3

Presentation of this teaching component

"I am convinced that to move forward, an object must be submitted to a force and the teacher told me that it is not necessary. Yet I have some arguments but the teacher does not seem to understand them...

"In a circuit with several bulbs, the current is necessarily used up since it makes them shine but still in physics they say that the current is constant: we do not speak about the same thing!"

According to current learning theories stating that human beings learn from what they already know, it is essential to attach particular importance to the knowledge that any student has necessarily built in his daily life even before starting any physics and chemistry learning at school. Research has shown how the prior knowledge of each student can be in conflict and / or coexist with what the student will have to learn.

In physics, it is especially crucial that first students learn gradually how to differentiate the physics knowledge from the everyday life knowledge. Then, this distinction will enable them to establish links between these two types of knowledge. This concern particularly helps students who are motivated by science, demonstrating intuition or imagination, but often unable to distinguish what is common sense from what is science.

Moreover, students spontaneously call intuitive explanations because these are often very efficient in everyday life. In physics classroom, students go without transition from one explanatory system to another one, which result of this lack of rigour results in a work whose structure does not match the teacher’s expectation. By asking students to specify their point of view (physical or daily), the teacher can help them to become aware of their own processes and to avoid offering an answer that is not recognized as a response in “physics”.

The interference between the two types of knowledge can be beneficial and constructive of meaning if it is handled as such. For this, the teacher must have the resources to make students’ initial ideas emerge in the classroom and to situate them in relation to physics.

In the light of this analysis, it is therefore logical to regularly propose activities allowing students to express their own ideas on the studied topic, taking possibly support on some classic materials or devices (daily or not). This may consist simply of a request for interpretation so as to elicit and to discuss the involved explanatory systems.

These activities may have several objectives, not exclusive:

• to allow students to become aware of their initial ideas;
• to rely on the students’ initial ideas to build physics knowledge;
• to illustrate the possible relevance of the physics model in relation to initial ideas.

This work is all the more effective as the teacher anticipates the students’ ideas that may occur. Each theme of classic physics teaching has been investigated, offering on the one hand the most widely shared ideas depending on the student’s age, and on the other hand situations and problems that are the most conducive to reveal them (for example working on electrical circuits with several identical bulbs to put in question the idea of current consumption or to fight against the idea of ...).

The emergence of ideas is not a goal in itself but an essential means of learning in order to make the student able to understand physics and to establish links between these two types of knowledge.

To go further

Knowledge of physics and knowledge of daily life

Justification and detailed choices made

Drawing on current theories of learning which posit that human beings learn from what they already know, we place particular importance on knowledge that the student has inevitably acquired from everyday life before starting any study of physics or chemistry. Research in diverse teaching areas has produced many findings on the subject of knowledge built up by students in their day to day life. In particular, it has been shown to what extent a student’s prior knowledge can conflict or coexist with what is taught, in every instance generating student output not conforming to that expected by the discipline.

The relation between knowledge of physics and knowledge of daily life must be taken care of in order to guide the student and reduce arbitrariness in physics classroom.

Differentiating between knowledge of physics and what works in everyday life to allow the student to pass from one to the other according to context and issue.

Little by little, the student must learn to differentiate their knowledge of physics from what works in everyday life in order to subsequently be able to establish the connections between these two types of knowledge (for example speed, acceleration and energy). This concern is crucial to help certain science-motivated students possessing intuition or imagination but unable to distinguish between common sense and science. Moreover, their system of explanation being often rich and without any apparent flaws, they refer to it confidently and spontaneously. Within the framework of physics teaching, they pass seamlessly from one explanatory system to another, which sometimes produces answers formulated in scientific terms but still expressing daily ideas.

This lack of rigour results in work whose structure does not correspond to that expected by the teacher.

The interference between these two types of knowledge, as problematic as it may seem for the teacher, can however be beneficial and constructive if taken charge of. This interference can manifest itself in two ways: firstly in common vocabulary with different meanings. Terms used in physics are often the same as those used in everyday life, but their use is much more rigorous and precise in physics. The scientific and everyday registers are different, even if there is some overlap. We have only to think of terms such as force, energy, power, heat or light, which all have various meanings in everyday language but are more precise in physics teaching. Even an expression such as “material object”, designating elements of the material world has a different meaning. An object is commonly something which can be manipulated, which is why the Earth can be an object for physics but not in an everyday sense.

Secondly in terms of intuitive reasoning or initial ideas. Initial ideas which can classically come up for physics study cases have now been relatively well established and formalised by research in many domains of physics. Facilitating the expression of these ideas and taking them into account will be examined in more detail in the 3rd Cornerstone.

Let us make it clear that the distinction between points a and b above is obviously a simplification because these two aspects influence each other. Common usage of certain terms creates a highly reinforced meaning in everyday life, to the extent of inducing classical reasoning: for example, energy is something to be consumed or produced or something you can lack; force is a property attributed to objects or more often to living beings, which can weaken or strengthen; sound is something which travels and spreads through all available
space a little like a gas does. The role of metaphors and analogies is crucial in this interaction between everyday meaning of a term and the construction of intuitive ideas which may give rise to a reasoning which is sophisticated but incorrect from a scientific point of view.

Consequences for the design and analysis of activities

We believe that the tensions between ‘everyday’ knowledge and scientific knowledge (in this case for physics and chemistry) - sources of misunderstanding between student and teacher and of learning difficulties - must at least be touched upon to create a pedagogy. They may even be drawn to the attention of the student so that they can become aware of their own learning and of the field of operation for the knowledge they are to acquire. Pointing out these differences is easy, particularly during the introduction to a class and in a physics context of a term already used in everyday life (weight, energy, force...). The gap between common usage and physics usage, when explained and taken care of, can help students over their difficulties.

(1) from everyday life, but with a different meaning to that used in everyday language e.g. Energy, force, pressure, power, action, to act, direction, weight, mass, acceleration or to accelerate etc. Although less common, this can also be true of phenomena such as dispersion, reflection, conservation...

(2) specific to the discipline: conduction, gravity, potential or kinetic energy, angular velocity etc; these terms are used by students as they learn.

(3) from everyday life which often have similar or identical meaning to everyday language e.g. car, measure, to fall, to touch, to vibrate, to become etc.

(4) used almost exclusively in physics lessons by students e.g. air table, wave machine, multimeter, oscilloscope, signal generator, etc.

See right-hand figure 1 to situate the four categories discussed. The expressions in case (1) and (3) are thus used in both contexts. When used to refer to concepts (case 1), the meaning is often different (e.g. to accelerate or weight, an exception being vibration). When used to refer to objects or events (case 3) the meaning is often similar or identical. In this case, however, it should not be forgotten that in physics, some objects are used in a very specific way compared to in everyday life.

It is as if physics was taking everyday objects to make them into ‘physics objects’. For example when we ask a student why the book on the table is static, he may be very surprised to hear an object not designed to move described in this way. The context into which the object is implanted is entirely dictated by the point to be taught and can generate a sizeable feeling of arbitrariness. It is therefore in case (1) or more rarely in case (3) that interference between ‘physics usage’ and ‘everyday usage’ may be the most troublesome while teaching, in that it can be a source of ambiguity for the student.

We certainly do not intend to make it sound like there is a correct and an incorrect use. Everyday use is not a wrong use, the proof being in its functionality (if in the street I ask my direction, anyone will understand me, yet the word is not used in its scientific capacity). We prefer to specify that, according to the context (everyday or scientific), some uses may be inappropriate. Which means:

• Distinguishing different usage contexts and different meanings according to the context (for examples, eg. spring and mass, acceleration...);

• Avoiding ambiguity of context when asking a student a question (stating whether a physics-related or everyday answer is expected) or using ambiguity to provoke a class debate;

• Stipulating the way in which the meaning is used when teaching even if little by little the students understand at their own speed that in physics class the term is used with the discipline’s denotation.

In the light of this analysis and the hypotheses formulated, it is thus logical to design activities at the beginning of a chapter which will allow students to spontaneously air their ideas on the subject at hand, possibly making use of some classical material situations. This may consist simply of asking for a description in their own spontaneous words, indicative of how they picture the situation and the meaning of the terms they use. These activities may have several non exclusive goals:

• Allow the student to develop awareness of initial ideas;

• Build on initial ideas to construct knowledge of physics and in particular acquire the capacity to formulate a pertinent description of the situation as far as the physics aspect chosen is concerned;

• Possibly illustrate the pertinence of the physicist’s model with regard to initial ideas.

Consequences for the teacher's attitude in class

The teachers pass from one context to another without problem. Moreover, as spokespersons for their discipline, they use words as a physicist would. This may seem obvious to them, but it requires a certain vigilance where the student is concerned, notably when starting to learn physics. This necessary vigilance on the students’ part may in some cases create a difficulty that the teacher must recognize as such. In order to be able to recognize and/or anticipate this difficulty, it is in the teacher’s best interests to be aware of it beforehand.

In some cases, the teacher may even lose sight of the semantic shift which occurs when a term from everyday life is imported into the context of the discipline. For example, there is obviously a link between direction in the physics sense of the term and direction in everyday language, but the nuance could be a source of no little misunderstanding and confusion for the student. Other examples: power, velocity vs speed, weight vs mass...

For the teacher, awareness of these different meanings when preparing and teaching a session will allow him/her to constantly monitor language and will therefore be a real pedagogical tool to promote students’ understanding.

It is therefore very important in class for the teacher to make the effort to spot the difficulties related to this issue and to let the class know about them. This will only be possible if the teacher has a thorough knowledge of each student’s written output when working in small groups.

Over and above mere words, everyday-life reasoning may not suit science or at the least not be nuanced enough. The teacher should thus point out discrepancies or even contradictions in such a way that the students will be aware and careful of them. By asking them to state from which point of view they are coming (the physicist’s or everyday life) the teacher can help the students to notice the way they work.
Taking into account the contexts of usage of physics terms

Lyon: Document 4

Presentation of this teaching component

“My physics teacher tells me a force is a trick that can’t be consumed, and yet when I feel exhausted by efforts I have no force left!”

The frequent usage in everyday life of certain terms used in physics is strongly associated with common reasoning:

for example the energy is something that can be consumed, produced, or that we can lack of; the force is a property of a person, animals, objects, which can run out or increase... The role of the language, of metaphors and analogies is crucial in this interaction between the everyday meaning of a term and the construction of intuitive ideas that are sometimes incorrect from the scientific point of view. This card thus proposes a deepening, centered on language, of a more general problem: the articulation between students’ initial ideas which are expressed in everyday language and physics knowledge to be learnt.

At high school, many terms used in physics are also used in everyday life but their usage is made in a much more rigorous and precise way in physics: we can think of terms like weight, force, energy, power, heat, light, that have a variety of meanings in everyday life and a precise one in physics. For example, an object in the common sense is something we can hold, that is why Earth, which can be an object in the sense of physics is not one in the common sense. To do physics often requires “to talk physics” (or talk like a physicist) with words already known in the ordinary language. As for other subjects, learning physics thus implies necessarily getting familiar not only

with the vocabulary which is specific to it but also with the usages specific to the discipline of terms used in everyday life.

The gap between common usage and usage in physics being an important source of difficulties, it is indispensable to clarify in class the various contexts of usage and the various meanings. To become aware of these various meanings allows the teacher, when preparing a session and when teaching, to exercise a constant vigilance as for the used language and thus constitutes a real tool to facilitate students’ understanding.

It is not a question of letting the students believe that there is a correct and an incorrect usage. The common usage is not a misuse, its functionality being the best proof (if I read in newspapers that energy is lost because buildings are not well insulated, everybody understands me and nevertheless the meaning of the word is not the scientific one). It is advisable on the other hand to explain to the student according to the context (common or scientific), one usage might be inappropriate. Thus we have:

• to distinguish the various contexts of usage and the various meanings according to the context;

• to avoid the ambiguity about the context when we ask a question to the student (by specifying if we expect an answer from the physics point of view or from the common one) or to admit the ambiguity so as to make it a subject of debate in the class;

• to specify the meaning with which we use the term when we teach it (even if gradually the student understands that in the physics class, the term is used with the meaning of the subject).

To go further

Knowledge of physics and knowledge of daily life (refer to text for same title on page 26)

The design of curriculum for promoting inquiry and argumentation

Santiago: Document 4: Designing curricula and resources that consist of authentic scientific inquiry

Presentation of this teaching component

“We liked it to feel as if we were real scientists” (9th grade student, from Luis Fernández classroom, about the experience of carrying out investigative projects).

Inquiry and argumentation are placed at the centre of innovative curricula. Recommendations about the features of curricula for promoting inquiry and argumentation include:

• A curriculum organized around authentic activities, which are characterized below.

• Problem-based learning providing structure for the curriculum.

• The tasks involve a certain amount of experimental, hands-on activities.

• Resources are designed to support the development of scientific practices, in particular argumentation (knowledge evaluation), modelling (knowledge construction) and communication.

• Depth is preferred over breadth.

• They are contextualized and relevant, or may be perceived by the students as relevant for their life.

• To be solved they require that students engage in inquiry procedures.

The activities that students perform when they are engaged in scientific inquiry have been discussed in Santiago document 1. The focus in this document is the characterization of authentic activities that in our opinion share these features:

• They constitute problems, which have not an obvious answer, not just rhetorical questions.

• They are contextualized and relevant, or may be perceived by the students as relevant for their life.

• To be solved they require that students engage in inquiry procedures.

• They are designed in order to produce a diversity of outcomes, to involve the consideration of a plurality of explanations.

It may be noted on the one hand that the relevance of the task does not mean that it needs to be a real issue. It could be, but it can be also a problem designed for the classroom, as long as its relevance is apparent. On the other hand, the diversity of outcomes means different degrees of openness: in some cases, as in the example discussed below, and in many socio-scientific questions, there is not a single “correct” solution. In other cases, as in causal explanations, there is only one answer corresponding to the scientific view, and what is relevant is the consideration of a plurality of potential explanations.

To go further

Designing authentic activities

From these dimensions about the design of curricula and resources one, the design of authentic activities, is selected for a detailed discussion.

The following examples are drawn from the work of Cristina Pereiro in her doctoral dissertation, an action-research study about her own classroom (Jiménez- Aleixandre & Pereiro, 2002).

The context is an 11th Grade classroom, in the night shift consisting of 38 students (should be...
Bristol: Document 2: Setting Tasks to Produce a Diversity of Outcomes

This section highlights the importance of designing authentic classroom activities with a diversity of outcomes and the challenges that the teachers faced in terms of design and management of the related lessons. The practical suggestions are provided and exemplified with Bristol teachers’ implementation of science experiments.

Designing the authentic classroom activity with a diversity of outcomes

“Most students think there is usually a ‘right answer’ in the science lessons and they are expected to find it in teacher’s discourse.”

Scientific inquiry often faces diversity of explanation, theories and models. Scientists reason through such diversity using evidence and justifications to conclude which alternative can be deemed to be the most validated. Science is a process of seeking the ‘best-fit’ explanations and models of the phenomena. Moreover, “Diversity is grounded in a view of knowledge as socially constructed through challenges brought about by differences in perspective. The diversity supports the evaluation of alternatives and students’ engagement in argumentation” (Erduran & Jimenez-Aleixandre, 2008, p.100).

The approach on diversity of outcomes requires lesson materials to be embedded in a plurality of explanations, with no “right and wrong” answers. Through engagement of such diversity of outcomes in scientific information students will gain an understanding of the nature of scientific inquiry and experience “authentic science”. However, in current science classes, students have not been offered the opportunities of experiencing science activity with a diversity of outcomes, which influenced the students’ views of the nature of science. For example, according to Bristol teachers’ experiences, students have been used to perceive science as “a bunch of facts” and always expect to find “one exclusive answer” to the problems in class. Such misconception about the nature of science affects the students’ view of science and also discourage their critical thinking.

“used to have tendency to one truth… it [HSW] opens up. [HSW enables] Kids can see things from different ways. Science is not a body of language… something you learn (about science) are going to be wrong. It [science] is long-term thing. Kids need to realize we might be wrong as several years ago the scientists did in the past.” “kids’ idea of science could still be about ‘facts’ while the science is not. Need to tell them science is all about the process and qualifying how right or true under certain circumstance.”

“we need to show them [the students] the process.”

Promoting a diverse set of outcomes in science lessons means that science is represented in its social, historical and cultural context. When we look at the history of science or study of scientific contexts, we witness that science advances through debate and discussion of alternative explanations. It is through critical evaluation of evidence, methods and potential theories that scientists indeed “do” science. Teachers can make science accessible to the dynamic face of science by offering evidence with multiple connections to students’ personal experiences and encouraging students to consider multiple views of phenomena.

Diversity can also offer the opportunity to include all students in lessons and allow them to contribute to the agendas of the classroom on the basis of their own ideas and interests.

Achieving a diversity of outcomes in the science classroom is also important in relation to practical or experimental work. Often in science lessons, students follow cookbook style recipes that are dressed to look like scientific inquiries. In these scenarios,
students’ roles are reduced to following the “recipe” without being engaged in the modes of acting and thinking that characterise scientific inquiry. For example, in authentic scientific investigations, scientists do not know the outcome of their experiments nor the particular methodology that is followed to find out about a research question. In scientific inquiry, there is ongoing evaluation of methods, evidence and interpretation through argumentation around multiple sets of accounts. For students to gain appreciation of science, teachers need to design activities to help students draw critically evaluated conclusions based on their own investigations. Based on the Bristol’s workshops, the teachers realized that with little modifications of traditional practical activities, teachers can offer more learning opportunities to the students when activities are revised with an argumentation framework in mind. For example, one of the teachers designed an open-ended experiment using familiar frameworks on solutions.

To go further
Lesson dissolving salt in water

One of the Bristol teacher conducted a lesson on whether or not types of instruments used has an example of evidence on how salt dissolves in water. The class was instructed to get into groups and design an empirical investigation to answer a particular question; conduct an experiment to collect data; and draw conclusions based on the collected data.

Based on the interviews that the teacher conducted with pupils, it emerged that pupils enjoyed their ownership of the research questions and experiments they designed. This open-end investigation produced a diversity of results around which arguments could be constructed. However, some pupils experienced difficulties in connecting the aim of the experiment to the process. They also needed support in communicating and reporting what they have done in the experiment. In terms of the scientific inquiry aspects, some were confused about the meaning of a fair-test (for example, to evaluate the validity and credibility of their experiments). In the teachers’ group discussion of this example at the workshop held at the university, the teachers suggested that putting the topic of dissolving in an everyday context might help with some of the difficulties encountered. Inspired by this particular discussion in the workshop, another teacher designed a related practical activity to invite students to investigate whether the different shapes of mugs will influence how fast the hot chocolate dissolve. The primary objective of this lesson also was to let pupils design, carry out and evaluate their own investigations. Without pre-determined answers, students are encouraged to carry out the experiments to test their hypotheses and were guided to draw conclusions based on the data they collected.

Bristol:
Document 3: Defining and Representing Science in Context including the Social, Historical and Philosophical Dimensions of Science

This section addresses issues of impact of socio-historical and philosophical contexts of science on students’ understanding of nature of science and learning the scientific concepts. Challenges in the teaching of such approaches are acknowledged and practical suggestions are given through a classroom debate activity designed by a Bristol teacher.

“The over-simplified history of science being presented in the curriculum will mislead the pupils’ understanding of the nature of science.”

Presenting science to secondary pupils in a decontextualised manner may lead to wrong stereotypes and misconceptions about science and scientists (e.g. Mamlok-Naaman et al., 2006). Numerous arguments have been made to align science education with a range of perspectives on science including perspectives from philosophy of science, cognitive science and sociology of science (Duschl et al., 2006). As an example, Erduran (2007) argues that philosophy of chemistry could provide useful insight into how nature of laws can be problematised in the science classroom considering perspectives on how philosophers can considered what counts as a ‘law’.

The incorporation of philosophy of science in science education has been advocated for several decades. Yet the overlap of chemistry education research with revived efforts in the application of philosophy of science to science education has been minimal. For instance, minimal attention has been paid to how philosophy of chemistry can contribute to the theory and practice of chemical education (Erduran & Duschl, 2004). The science curriculum and teaching resources should acknowledge the nature of scientific knowledge and inquiry, and present science in context such that pupils can see how science works and doesn’t work. The Bristol teachers indicated that the typically science is over-simplified in the curriculum when it comes to history of science and stories of scientists. For example, teachers pointed out the following ideas:

“...to delete all the errors on the way [history of science] as well... so you can’t see all the stupid things scientists have done as well... the stupid answers which is part of trial and error”

“condensing down tremendous scientific history to something you taught very briefly...it is a bit like top-down designed to simulate what’s happened over long-time scale in a quite artificial setting.”

Despite the fact that the Bristol teachers acknowledged the importance of presenting science in context in the science classroom, they also indicated that practical implementation of these ideas are still challenging. For example, the issue of lack of teaching resources and the conflict between implementing philosophy of science to over-loading contents in the curriculum. The group discussions with Bristol teachers suggests instead of “adding something extra”, the socio-historical context should be integrated into the traditional science classrooms. The design and implementation of traditional subject content could be enriched through contextualisation in its socio-historical contexts.

To go further
One of the Bristol teacher designed a classroom debate activity aiming to engage students in argumentation, in terms of a) distinguish evidence and opinion; b) discuss the reliability of evidence and c) examine the source of evidence. The activity starts with a question of “is chocolate good for us”, then asks the students to choose 3 pieces of evidence for and against the claim of

From observation to investigation

Theo has just stirred hot chocolate powder into his mug of hot water. He notices that it dissolved slower than yesterday and thinks it might be something to do with the shape of the mug.

What is the aim of this investigation?
“chocolate is good for you” from the provided “facts cards”. The students are also asked to survey the opinions of 3 classmates on this topic and back up their opinions by at least one reason. Inspired by the teachers’ questions, the students are asked to discuss the validity of their arguments and the reliability of the evidences they choose. With the provided writing frame, students write a report of whether they think chocolate is good or bad for them.

This activity is set in the context of students’ everyday life which makes the task relevant to students. Moreover, the social scientific topic offers the students’ example of using scientific knowledge and scientific thinking to deal with social problems, including everyday problems related to nutrition and diet. The content of “fact cards” includes the information from a range of sources, such as the chocolate factory account, the news and the science research. The activity reveals the nature of scientific activity as an ongoing process of drawing conclusions based on collected data and weighing of data with respect to the reliabilities of different sources.

Is chocolate good for us?

What do you think?
Put your answers in your books.

The classroom strategies to promote inquiry based teaching and argumentation

Lyon:
Document 5: Organising debates and institutionalising

Organizing debates and institutionalizing

Presentation of this teaching component

“Pfft, anyway my feeling about physics is that it is not even worth discussing, everything is fixed, it’s like that and we have to learn even if it seems odd…”

To make physics less arbitrary, it seems essential to start from students’ proposals on the studied situations. This has the added advantage of providing an image of the learners’ activity. This choice suggests to organize or to allow the emergence of debates within the classroom as often as possible.

The diversity of ideas and elements of knowledge from the phases of thinking and writing is the starting point of the discussion for the whole class under the teacher’s responsibility. This debate can emerge rather easily: the teacher questions the first group then a second group spontaneously suggests a counter-argument. To ensure the richness of the debate, the teacher can ask various groups to give their solutions, for example by writing them on the blackboard. To stimulate discussion, the teacher must rely on what s/he observed while small groups are working or on classic ideas which can emerge. Knowing this diversity of ideas enables the teacher to manage the debate without taking a position. The arguments are exchanged between the different students (or groups), which allows to feed the discussion and to identify possible outcomes that could make consensus. It also enables students to make the effort to formulate their ideas clearly and to take the responsibility for them. Students must also realize that a wrong idea is worth discussion because it helps to advance the debate and to make the conclusion less arbitrary.

The closure of the debate can take many different forms. Often the conclusion of the discussion allows the teacher to introduce students to the knowledge that should be acquired according to the official recommendations (institutionalization). Indeed the debate enables to justify what will be accepted by explaining why certain ideas have been abandoned (inconsistent with a prior law or a chosen hypothesis, poor consideration of testing, inadequate understanding of the meaning of a word physics...). This phase is often viewed by the students as a “correction” of an activity.

In other cases (prediction without theory, expression of intuitive ideas...), there is no “right” answer expected, which will trigger the need for additional exploratory phase: the response to the debate will be given for example in an experiment that will validate or invalidate a prediction, or will be given later when other elements of knowledge will have been acquired. In all cases of debate closure, it is important that the teacher should have prepared some written sentences that are clear and usable in the further steps of teaching.

To go further
Learning from mistake

We emphasize the formative role of mistakes. Being aware of his/her own thinking, of other arguments and of those given by physics help to learn physics. This role has been introduced with the comments on “working in small groups” which allows student to proceed by trial and error and more generally make their ideas explicit and debatable. More generally, as we discuss above, learning is favoured if students have the possibility to make their proposals explicit to others and to discuss them, and also to understand the physics proposal with argument if it is not his/her own proposal.

This comment is particularly focused on the students’ written track of their work, which builds up meaning and helps them realise their thought process. In our opinion, it is in the teacher’s interest to highlight the contribution to

learning of mistakes. During institutionalization, the teacher could suggest neatly crossing out mistakes instead of erasing them completely, and then adding the correction to their own answer in a different colour.

The teacher should also take time to explain to the students how to manage homework and how the different types of documentation can be used efficiently for revision. He/she could emphasise the necessity to re-read (or re-do) an activity as these are not restricted to classroom use only. During the institutionalization stage, students will no doubt notice discrepancies between the work they have produced and the institutionalized knowledge. They will more often than not view these discrepancies as an error in their written work. E.g. they could have made an assumption which turns out not to be true, or perhaps they didn’t use the model with enough thought. Normal teaching practices, and the negative connotations of mistakes that are given in school, push students to eliminate them in their notebooks (when they are aware of them). By leaving a trace of a mistake, one is more conscious of it than if it was erased. In addition, seeing one’s former mistakes helps one realise the progress that has been made.

Lyon: Document 6: Making students cooperate in small groups

Presentation of this teaching component

“In physics, when the teacher gives us an activity, everything seems foreseen in advance, so you simply have to guess what he wants us to say we don’t even have time to discuss between us”

Many research studies show that knowledge construction is favoured when students have the opportunity to cooperate and debate about the situation under study. For that, regular work in small groups (two, sometimes three or four) is particularly adapted, provided there is an explicit incentive for cooperation. This cooperation leads to include moments of oral exchanges and some of writing to formulate new ideas which then can be acquired.

This work in small group does not exclude students’ personal reflection, at any time of teaching. The objective of cooperation must be explained to the students: to exchange their views and proposals in order to reach agreement if possible and to write down a common response of which each student keeps track. This process leads students to clarify and refine their ideas. Thus, this phase of debate allows each student to explain his/her point of view or his/her daily life knowledge, to defend it, to confront it with his partner’s one and perhaps to modify or develop a new view.

Of course, this phase of work in small groups requires much time left to students to enable them to proceed by trial and error and to try and write the best formulation. During this phase, even if the teacher has to remind the students to whisper, s/he must accept a rise in the noise level in the classroom; moreover he should check that the students’ exchanges are about the topic proposed.

To take advantage of this special time to understand the students’ approaches, the teacher listen very carefully to the students and observe their writings. S/he may occasionally intervene to clarify the instruction or help students not to stray into the wrong runway, but shall in no way break the students’ discussion or provide clues about the expected response. In his/her talk, the teacher must try to understand the students’ views by asking them questions and not directly initiate a discussion of their solution. Observing students’ outputs is crucial for the teacher because it allows him/her to identify the different views of students and their difficulties in order to bring them out during the debate that will follow.

To go further

Supports helping autonomous work in small groups to learn physics

In the following text, the emphasis is only made on one aspect of the cooperation: that is the importance of writing in relation to oral discussion.

Students’ written documents

With this teaching practice where students have to frequently work in small groups to develop new knowledge, in a rather autonomous way, it is important to help them to structure their written source of information and other written documents. Students have three types of document at their disposal for each chapter, to be kept in a file or exercise book:

1. Worksheets including:
   • text provided by the teacher on an activity
   • student’s personal written work (resulting from pair work).

   In order for each student to have a clearly structured file, he/she should cut the text from each activity, stick it on the worksheet and write any answers under the text. Annotations can be made on these sheets, in a different colour for example, following information sharing as a class (e.g. errors made and further information from the teacher given at the end of an activity). Students should get used to leaving enough space on their worksheets to insert these annotations, which can be numerous.

2. ‘model’ sheet

   We consider it is essential that students have access to a written documentation presenting the theoretical elements to which they will need to refer, the relation between quantities, the modelling tools. This sheet should be clearly filed in an exercise book. If the model has been handed out in different parts, it should be easily distinguishable by using a colour code or a summary sheet (which could be handed out at the end of the chapter on coloured paper).

3. Exercise sheets including:
   • the solutions found by the student
   • the original questions if the teacher uses problems which are not in the textbook.

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The student should learn to manage these different types of documentation, with help if necessary from the teacher, especially at the beginning of the school year (checking the appearance of exercise books/files is a good way of encouraging students to manage them carefully). It could be useful to share this way of working with the parents too so that they can help if necessary. Let us note the formative role of mistakes. Keeping written track of their work gives students the opportunity to build up meaning and help them realise their thought process. In our opinion, it is in the teacher’s interest to highlight the contribution to learning of mistakes. During institutionalization, the teacher could suggest neatly crossing out mistakes instead of erasing them completely, and then adding the correction to their own answer in a different colour. The teacher should also take time to explain to the students how to manage homework and how the different types of documentation can be used efficiently for revision. He/She could emphasise the necessity to re-read (or re-do) an activity as these are not restricted to classroom use only.
This section focuses on the importance of creating science learning environments that encourage mutual responsibility for knowledge construction between the teacher and the learners. An example of an open-ended experiment is provided highlighting how the pupils were empowered in their learning of science.

Create classroom environment to encourage mutual responsibility for knowledge construction

“Students used to be passive information receiver in the science classroom, which they complained they had no time to think in the class.”

According to constructivist theories of learning, students need to be active learners in the classroom. In terms of construction of scientific knowledge, then, students will take an active role and knowledge will be co-constructed together by the teacher and the students. This approach to students’ role in construction is in stark contrast to traditional models of learning where the students are passive receivers of knowledge transmitted by the teacher.

Substantial body of literature demonstrate that the passive knowledge receiver role of students could mislead the students’ understanding of science as a collection of objective facts and inhibit their understanding of the nature of science. In this sense, the transmission model of learning deprives students from learning opportunities and experiences to understand scientific inquiry and argumentation.

In order to achieve a more active role for students, the role of the teacher needs to undergo a fundamental shift from the “knowledge deliverer” to the “co-learner” with the students, from the leader to the guide or facilitator role. Such shifts often pose challenges for teachers who might consider themselves as the “expert” who represent the correct scientific knowledge in the classroom. Teachers might have issues with letting go of control of how knowledge gets managed. As some of the Bristol teachers said:

“I feared to let go my control, the class can completely go nowhere.”

“It’s hard for teachers to step back … and also the students got used to getting help… so they expect to get direct help.”

The implication is that teachers need to be supported through professional development to engage in the adaptation of novel strategies for teaching and learning. For instance, professional development programmes need to be clear in communicating to teachers that the decentralisation of teachers’ role in teaching and learning doesn’t mean that teachers’ input is reduced but rather that the expectation is more skilful scaffolding of students’ learning. Knowledge and strategies of constructivist approaches to teaching and learning need to be integrated into professional development agendas along understanding of subject knowledge and classroom management.

Effective implementation of different roles for teachers and students in the classroom creates new demands on students as well. Not only the teachers need to be trained on how to teach in a different way, but also the students need to be made aware that they are now learning in a different way. In other words, norms of constructivist teaching and learning need to be embedded in the classroom culture as a whole, not just located in the teachers’ mindset.

Students need to be aware of their own responsibility in knowledge construction and be inspired to be active learners who are in charge of their own learning.

To go further

One of the Bristol teachers conducted an activity on “viscosity” with secondary science students (Erduran & Yan, 2009). The aim of the activity was to engage the students in the design, evaluation and presentation of a practical approach to understanding what factors influence viscosity. He used video clips to initially motivate the students in understanding why viscosity might be relevant to everyday life in the first place. He demonstrated how oil in car engines can get hot, reducing the performance of the engine. He subsequently modelled viscosity by pouring honey between wooden slabs and demonstrating the role of friction and generation of heat during friction. He thus called this activity “Runny Honey”. The naming of this activity in a student-friendly manner got the students motivated and involved in the lesson in ways that they most likely would not be had the lesson be called a lesson on viscosity. The students then were asked to design investigations to find out what factors influenced the “runniness” of honey. Students got into groups and planned experiments that they subsequently conducted. For instance, some groups timed how long it takes drops of honey at different temperature moving down an inclined plane. At the end of the lesson, students were asked to evaluate their experiments as well as their own learning. The teacher produced writing frames to facilitate all phases of the lesson.

In this lesson, students shared the responsibility with the teacher in generating a plan for an investigation as well as criteria for the evaluation of results and their own learning. They took on an active role in scientific inquiry. The teacher monitored the group discussions and experiments, continuously giving feedback to students. His post-lesson reflections indicate that his choice of multiplicity of outcomes in the experiments were intentional. He said:

“There was evidence-deficiency and this was on purpose to give the pupils an opportunity to argue about their variables and results.”

Overall, the lesson integrated aims of inquiry and argumentation skills with students’ active engagement not only with these goals but also with respect to their own learning. The questions on the “evaluation of your learning” sheet, for example, placed students in the mindset of needing to engage in their own learning, thus changing the role of the students from being passive receivers of knowledge to active participants in the subject matter and in learning.

Project partners: