PROMOTING INQUIRY IN MATHEMATICS AND SCIENCE EDUCATION ACROSS EUROPE

CAPACITIES

# The PRIMAS project: Promoting inquiry-based learning (IBL) in mathematics and science education across Europe

## PRIMAS guide for professional development providers

**PRIMAS is developing a guide for professional development providers that offer courses for mathematics and science teachers in IBL pedagogies. The guide outlines our approach and important concepts relating to the IBL professional development courses. As the project runs until 2013 this report is a first version of the product that will be available.**

**www.primas-project.eu**

*The project PRIMAS has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 244380.*

SEVENTH FRAMEWORK PROGRAMME

PRIMAS

PROMOTING INQUIRY
IN MATHEMATICS AND SCIENCE
EDUCATION ACROSS EUROPE

# GUIDE FOR PROFESSIONAL DEVELOPMENT PROVIDERS

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PROMOTING INQUIRY IN MATHEMATICS AND SCIENCE EDUCATION ACROSS EUROPE

# Introduction

PRIMAS is the acronym of the European project *Promoting Inquiry in Mathematics and Science Education across Europe*. Founded under the 7th Framework Programme, PRIMAS brings together mathematics and science educators from 14 universities in 12 different European countries.

PRIMAS aims to:

- Provide insight into approaches to mathematics and science teaching that are motivational and enjoyable for learners
- Support teachers with inquiry-based learning pedagogies in mathematics and science
- Provide resources and coordinate professional development for teachers and teacher educators
- Support teachers, students and parents understand the nature and importance of inquiry-based learning
- Develop and work with networks of teachers and professional development providers in participating countries
- Analyse and understand current policies in relation to inquiry-based learning and inform and work with policy makers to support improved practice

PRIMAS will face a big challenge: working beyond local scenarios. Our aim is to reach the critical amount of teachers, students, parents and policy makers that will ensure a real and perceivable impact on daily teaching practices, students' learning, parents perception of school mathematics and science, and current and future policies.

Among the different actions PRIMAS will promote, the successful implementation of a wide scale and long-term professional development (PD) programme in every country is absolutely crucial. Teachers are probably the most important actors in promoting a change in the way mathematics and science are conceived and taught across Europe. And together with the support they will get from students, parents and policy makers, they are the only capable to make this change really happen.

In order to support teachers in this challenging and fascinating journey, PRIMAS offers a wide variety of resources and strategies for professional development, together with exemplary classroom materials. And you, as a continuing professional development expert, will have honour and the responsibility of accompanying some of these teachers in their professional and personal journey, offering support and guidance.

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**What will you find in this guide?**

This guide will offer you key knowledge about:

- *inquiry based learning*,
- teachers' continuing professional development, including professional development strategies,
- PRIMAS professional development resources and platform,
- strategies to guide and support teachers in their professional growth.

Combined with your expertise and the support you will get from the PRIMAS team in your country, we are convinced of the success of the professional development action you will organize and implement.

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# What is IBL?

In this section we will introduce key aspects of what is called *inquiry-based learning* (IBL) together with some exemplary materials.

## The aim

To offer a clear and shared understanding about what IBL is and how IBL looks like. This will guide the later development of PRIMAS professional development programme

## The outcome

You will get a clear understanding about IBL. This is the core message you will build with teachers throughout the professional development actions you will run.

## Contents

- Inquiry Based Learning (IBL)
- Classifying IBL situations
- Example: IBL lesson in mathematics
- Example: IBL lesson in science

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## Inquiry Based Learning

Inquiry Based Learning (IBL) is the term widely accepted to refer to a way of teaching and learning mathematics and science in which students are supposed to proceed in the way mathematicians and scientists actually work.

If we take a look to the way mathematics and science is taught in many classrooms, students' activity is often far away from the work of mathematicians and scientists. The Rocard Report (2007) draws this distinction between two approaches to teaching:

| The "Deductive approach" | The "Inductive approach" |
|---|---|
| In this approach, the teacher presents the concepts, their logical – deductive – implications and gives examples of applications. This method is also referred to as 'top-down transmission'. To be used, the children must be able to handle abstract notions, what makes it difficult to start teaching science before secondary education (ibid, p. 9) | This approach gives more space to observation, experimentation and the teacher-guided construction by the child of his/her own knowledge. This approach is also described as a 'bottom-up' approach.<br><br>The terminology evolved through the years and the concepts refined, and today the Inductive Approach is most often referred to as Inquiry-Based Science Education (IBSE), mostly applied to science of nature and technology. (ibid, p.9) |

In this report, experts[1] describe IBL as "the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments". Although we will use IBL both for mathematics and science education, it is worth to mention that in the field of mathematics education the term Problem Based Learning (PBL) is used more often.

In the same vein, other authors like Askew et al. (1997), Ernest (1991), and Swan (2006) distinguish, in the teaching and learning of mathematics and science, between:

- *A transmission approach:* teacher-centred, with students as passive recipients of information.
- *A discovery approach:* student-centred, where the teacher simply presents tasks and expects learners to explore and discover from themselves.
- *A connectionist approach:* student-centred, collaborative approach.

The next table (Swain & Swan, 2005) summarizes the main features of this three approaches, been the last one in line with our understanding of IBL.

[1] Based on Linn, Bell, and Davis (2004)

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| | Transmission | Discovery | Challenging |
|---|---|---|---|
| Views of the subject | a given body of knowledge and standard procedures. A set of universal truths and rules which need to be conveyed to students | a creative subject in which the teacher take a passive, facilitating role, expecting students to create their own concepts and methods. | an interconnected body of ideas which the teacher and the student create together through discussion |
| Views of learning | an individual activity based on watching, listening and imitating until fluency is attained. | an individual activity based on practical exploration and reflection | an interpersonal activity in which students are challenged and arrive at understanding through discussion |
| Views of teaching | structuring a linear curriculum for the students; giving verbal explanations and checking that these have been understood through practice questions; correcting misunderstandings when students fail to 'grasp' what is taught. | assessing when a student is ready to learn; providing a stimulating environment to facilitate exploration; avoiding misunderstandings by the careful sequencing of experiences | a non-linear dialogue between teacher and students in which meanings and connections are explored verbally. Misunderstandings are made explicit and worked on. |

Swain & Swan (2005)

In order to offer a deeper understanding about what is IBL and how it looks like, we will follow here the ideas and structure offered by Walker (2007).

If the students are supposed to work as mathematicians and scientists, the question is, *how do mathematicians and scientists work?*

To answer to this question, Walker (2007) poses a previous question: *what is science made up of?*

Following different sources, he argues that science contains three main facets:

**The scientific process**

Skills used by mathematicians and scientists when they are doing mathematics or science.

It is possible to distinguish between:

- Basic process skills: observation, classifying, measuring, communication, inferring and predicting.
- Integrated process skills: controlling variables, defining operationally, formulating hypotheses, collecting data, interpreting data, experimenting and making models.

When mathematicians and scientists are working, they bring into play several of these processes. A more detailed description of the scientific processes is offered in Fig. 1.

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**The scientific knowledge**

Mathematicians and scientists produce knowledge, ideas and concepts. These are usually formulated as hypothesis, theories and laws:

- A hypothesis is an idea or explanation for something that is based on known facts but has not yet been proved.
- A theory is an explanation of certain event, which is supported by many verified hypothesis. These hypotheses could be verified either experimentally or rationally deducted from previous results.
- A scientific law is a general rule that states what always happens when the same conditions exist.

Both hypothesis and theories must be falsifiable, which means that new discoveries or results could eventually lead to the reconsideration, and even a refutation, of an existing hypothesis or theory.

**Scientific attitudes and values**

Scientists have a set of values, beliefs and attitudes, which influence how they think and how they act: *science is empirical, science is tentative, experiments can be repeated, science is falsifiable, and science is self-correcting*.

Some of these could be applied to mathematics as well, although with some exceptions: although mathematics can be considered to be empirical to some extent, the kind of “experimentation” can differ significantly from the scientific one, but we will not go further here.

A traditional way to describe how scientists work is the well-known scientific method:

- Observation and description
- Questioning
- Hypothesis formulation
- Predicting
- Experimenting
- Conclusion

Without denying the usefulness of this ideal description for educational purposes, it is important to be aware of other ways scientists work, like trial and error, product testing, inventing, making models, or documenting, among others. Moreover, mathematicians, but also scientists, work very often in an abstract and logical level, where rational deductions predominate.

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Fig. 1. Inquiry based learning processes

Summarizing in this point, we could say that:

IBL is a way of teaching and learning mathematics and science in which students are invited to work in the way mathematicians and scientists work.

When students are involved in an IBL lesson, they need to put into play their prior knowledge and a wide variety of processes, like simplifying and structuring complex problems, observing systematically, measuring, classifying, creating definitions, quantifying, inferring, predicting, hypothesizing, controlling variables, experimenting, visualizing, discovering relationships and connections, and communicating (Fig. !).

## Classifying Inquiry Based Learning situations

A common misunderstanding is to confuse IBL with doing experiments or some practical work in the classroom. If the knowledge needed to conduct the experiment or to do the practical work has already been explained by the teacher and the experiment is just used to illustrate this knowledge, we could hardly accept this as a real inquiry-based learning situation. However, inquiry situations vary depending on the degree of openness of the situation as well as on the distribution of responsibilities between the teacher and the students.

Different authors have developed different classifications of inquiry-based learning situations. Walker (2007) explains some of these. Following his work, we will refer here only to two different classifications: a first one from Tafoya et al. (1980), a second one from Fradd et al. (2001).

**Tafoya et al. (1980) classification of inquiry-based lessons**

| Open | Guided | Structured | Confirmation exercises |
|---|---|---|---|
| The students decide both on the question to investigate and the method they use to get to an answer | The teacher provides the question but the students decide on the text method in which to answer it | Teacher provides both the question and the method, but not the outcome. | Teacher tells the students what the solution to the question is, and then gives instructions on how to conduct an experiment or some practical work to confirm the answer. |

Obviously, the last category ("confirmation exercises") could be considered as a distorted case of IBL, which indeed is not IBL at all.

We will reproduce here an example given by Walker (2007) that we found quite revealing:

**Lesson about the rate of photosynthesis in pondweed**

| Open | Guided | Structured | Confirmation exercises |
|---|---|---|---|
| Students are told to 'investigate the factors which affect the rate of photosynthesis in pondweed'. | Students are told to design and conduct an experiment to answer the following question 'how does light intensity affect the | Students are told 'how does light intensity affect the rate of photosynthesis in pondweed? Collect a lamp, a beaker, and a | Students are told 'the rate of photosynthesis is greater at higher light intensities. You will see this in the following experiment. |

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| | | | |
|---|---|---|---|
| | rate of photosynthesis in pondweed?' | sprig of pondweed, and set the experiment up as in the diagram provided. Observe how many bubbles of air come from the pondweed each minute when the lamp is at 10, 20 and 30 cm distance from the pondweed. Fill in this table.' | Collect a lamp, a beaker, and a sprig of pondweed, and set the experiment up as in this diagram. Observe how many bubbles of air come from the pondweed each minute when the lamp is at 10, 20 and 30 cm distance from the pondweed. Fill in this table. As you can see more bubbles of air are produced when the lamp is closer to the pondweed.' |

The second classification, which is more complex but at the same time more useful when thinking about IBL lessons, is the one offered by Fradd et al. (2001). These authors develop a matrix where the main features of an IBL situation are listed. Depending on who – the teacher or the students – takes the responsibility of what, they propose six levels of inquiry. The next table, adapted from Walker (2007), summarizes this classification:

**Fradd et al. (2001), inquiry level in IBL lessons**

| Inquiry Level | Questioning | Planning | Implementing | Concluding | | Reporting | Applying |
|---|---|---|---|---|---|---|---|
| | | | Carrying out plan | Analyse Data | Draw Conclusions | | |
| 0 | Teacher | Teacher | Teacher | Teacher | Teacher | Teacher | Teacher |
| 1 | Teacher | Teacher | Students /Teacher | Teacher | Teacher | Students | Teacher |
| 2 | Teacher | Teacher | Students | Students/ Teacher | Students/ Teacher | Students | Teacher |
| 3 | Teacher | Students /Teacher | Students | Students | Students | Students | Students |
| 4 | Students/ Teacher | Students | Students | Students | Students | Students | Students |
| 5 | Students | Students | Students | Students | Students | Students | Students |

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We have added the grey shadow just to visually stress how responsibilities are transferred from the teacher to the students as the inquiry level increases.

We agree with Walker (2007) in that this matrix is a valuable tool for teachers to understand how they can make their lessons more open. Moreover, it could be an useful tool to adapt IBL situations to students with different capacities or in different school levels.

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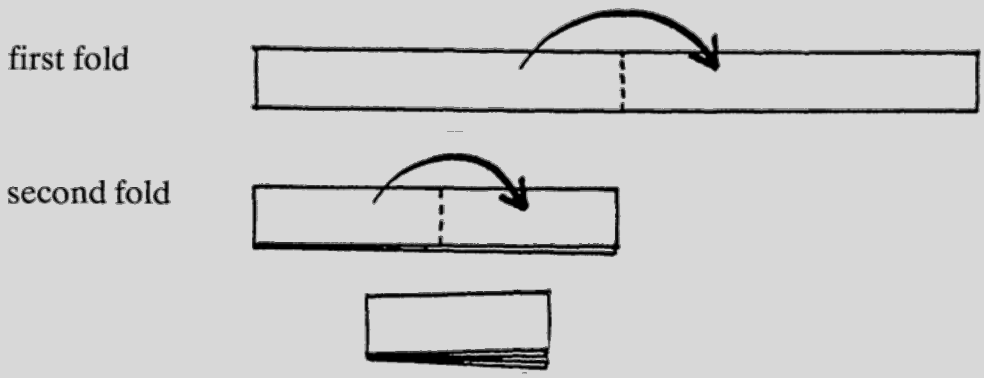
## Examples: IBL lessons in mathematics

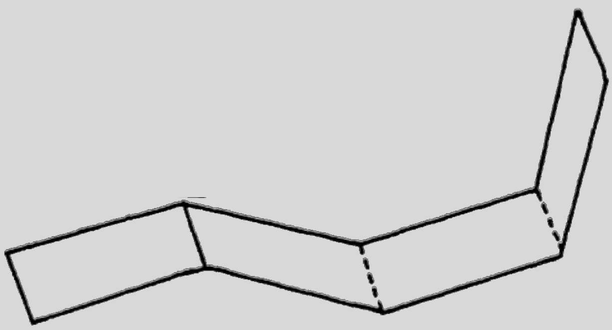
### ❶ *Paper folding*[2]

The *Paper folding* activity presents a situation in which students will investigate what happens when a scrap of paper is folded several times. The situation starts with a particular case, but then invites students to investigate other cases.

*Take a scrap of paper and fold it in half, and then in half again. In both cases you should fold left over right.*




*When the scrap of paper is unfolded, you will see 3 creases: one "up" and two "down".*



*What will happen if you fold the scrap of paper more than two times? Investigate the situation.*

*Try to fold the paper in a different way and explore the patterns in the positioning and number of your creases. Write about your findings.*

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[2] From "Problems with Patterns and Numbers", Shell Centre for Mathematical Education. This book can be retrieved from PRIMAS site (http://www.primas-project.eu )



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The problem presents a rich situation. Students can and should explore it, formulate their own hypothesis, test them, collect data, generalize them, build and validate models, formulate theorems, etc.

In the management of an IBL situation like this, teachers should let students time enough to actively explore the situation, in a non-directed and unhurried atmosphere. Teachers should avoid giving students results before they have the opportunity to find them. Moreover, they should support students in their inquiry process. When students' blockage appears, teachers should use effective questioning strategies that allow students to go further, instead of giving them "the correct answer".

In the "Paper folding" situation, playing with scraps of paper is neither incidental nor recreational. On the contrary, it is an essential feature of the problem. It will be like a little laboratory students will use to get into the situation, to start to understand how it works, to formulate their initial hypothesis, to empirically validate models, to argue and communicate, to be pushed into the background once they have build mathematical models that exempt them to carry out concrete manipulations, etc.

### ❷ *Signing task*[3]

The *Signing task* is based on a real situation that took place in Spain in 2006.

*In April 25th 2006, the Spanish party in the opposition presented in the Congress 4.000.000 signatures against a new law promoted by a regional government.*

*All Spanish newspapers published pictures with the big boxes and the 10 vans needed to transport the sheets of paper with the signatures to the Congress. Do you think there was a political intention behind this staging or all these boxes and vans were really necessary to transport the 4000000 signatures?*

[3] From LEMA Project (http://www.lema-project.com )

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The “Signing task” presents a different kind of IBL situation. It is a real and authentic situation. The results students will obtain will be important not only from a mathematical point of view but also from a social and critical perspective.

When working in the “Signing task”, students will have to simplify the situation, make estimations and formulate hypothesis, build models and validate them, argue and communicate using mathematical arguments, revise and refine their models, etc. At the end, the result will not be just a number but a whole statement about the situation, both supported by mathematical calculations and restricted by the hypothesis and assumptions made by the solver

## Example: IBL lesson in science

❶ *Hydration of legumes*[4]

In the *hydration of legumes* activity, students will face an open and unstructured problem.

*In a legume cannery (lentils, beans, chickpeas) there is a need to optimize the hydration process for improving the overall industrial process.*

- *Raise some key questions to guide your investigation*
- *Formulate initial hypothesis*
- *Design an experiment to test them, establishing which variables and conditions are you going to investigate and how.*
- *Carry out the experiment, collect data and chose the best one to represent them*
- *Analyze the main results and draw some conclusions on the basis of the available evidence*
- *Make a detailed report*

In this activity, Students’ will work in groups, exploring and structuring the situation, formulating questions and hypothesis, designing experiments and carrying them out,

[4] This resource is available at PRIMAS website (http://www.primas-project.eu )

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obtaining, representing and interpreting data and, finally, writing a report about their findings. At the end, a whole group session in which each working group presents their results could be used as a starting point for a debate about the situation and to identify key contents and processes students have been working with.

❷ *Germination*[5]

*Imagine that you work as a scientist in a biological research lab. One day your boss comes to you with a problem he wants you to answer:*

*'Global warming could be a big problem for farmers all around the world. The germination of some species of plants could be affected. Design an experiment to find out how global warming could affect seed germination in the spring, and if this will be a problem for farmers'.*

*You have to design and conduct an experiment to find out what effect global warming could have on seed germination. You should:*

- *Decide which experiments to conduct*
- *Decide which data to collect*
- *Do the experiment*
- *Make a poster showing your results and conclusions*

In this activity, students are told to investigate a situation: "how global warming might affect plant growth". They are neither told about the type of results they will get nor about the kind of experiment they should do.

In contrast with traditional teaching sequences, students will not just take a solution from a textbook. On the contrary, they will approach to a possible solution once they design and carry out their experiments; once they share their findings and discuss about them.

[5] From Walker, M. (2007). *Teaching Inquiry-Based Science. A guide for middle and high school teachers*.

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Why IBL?

In this section we introduce arguments that support a wider implementation of IBL pedagogies in mathematics and science classrooms across Europe.

## The aim

To justify why IBL has become currently a central topic in science and mathematics education

## The outcome

You will learn about reasons to argue in favour of a wider use of IBL pedagogies in mathematics and science classrooms

## Contents

- Reasons for a wider uptake of IBL
- Obstacles that hinder IBL

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## Reasons for a wider uptake of IBL

Inquiry Based Learning is not something completely new. Constructivist approaches in education have shown that students' learning is deeper and more meaningful if they have opportunities to explore rich situations (instead of routine exercises), if they are actively involved in classroom situations (instead of being passive learners), if they have the responsibility of monitoring their own learning (instead of learning step by step, following a linear sequence), if they find key mathematical and scientific topics (instead of just being told).

The main reasons for a wider uptake of IBL are related with the benefits students will get from this approach. According to different authors, the following benefits have been identified:

- IBL increases students' attainment in mathematics and science, with an even strong impact in students with lower levels of self-confidence and those from disadvantages backgrounds (Rocard report, European Commission, 2007).
- Students will remember and understand scientific knowledge better (Walker, 2007).
- Learning with understanding, which is supported by IBL, increases students' ability to use their knowledge in new situations and contexts (transferability of knowledge).
- IBL promotes higher order thinking skills and the development of key competencies.
- IBL provide children with opportunities to develop a wide range of complementary skills such as working in groups, written in verbal expression, experience of open-ended problem solving and other cross-disciplinary abilities (Rocard report, European Commisson, 2007).
- Students will learn how scientists generate knowledge and how the current body of scientific knowledge was developed and produced (Walker, 2007; Schwab, 1962). As a consequence, students will have a more balanced and realistic perception about science, its nature and the way it is created and developed.
- IBL has positive impact on students' attitudes and motivation towards science. They find mathematics and science more interesting and exciting, giving rise to a more positive view of mathematics and science.
- Potentially, IBL might have also an impact on students' willingness to go on studying scientific disciplines and getting involved in scientific careers.
- IBL approaches may be an effective way to increase girls' interest, self-confidence and participation in science activities (Rocard report, European Commisson, 2007).

Moreover, IBL has proven its efficacy with students of different abilities, and especially with students with negative attitudes towards science and mathematics as well as students with

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different capacities. In this sense, IBL can promote a more inclusive mathematics and science education, which will benefit society as a whole. Besides, IBL do not imply giving up the ambition of excellence. On the contrary, as far as IBL promotes learning with understanding that will emerge from meaningful situations where students are engaged actively, students will get a deeper learning of mathematics and scientific knowledge. Together with the development of an associated range of competencies and higher order thinking skills, students will be better equipped both as citizen and workers for the 21st century.

## Obstacles that hinder IBL

Despite of its benefits, inquiry based learning is not safe from criticisms, obstacles and problems that act as barriers for a wider uptake of IBL.

Anderson (1996) refers to:

- *Technical problems*, like teachers' limited teaching abilities, prior commitments (for example, to a textbook), the challenges of assessment, difficulties with managing group work, the challenges of new teacher roles and new student roles, an inadequate in-service education, among others.
- *Political problems*, including limited in-service education (i.e., not sustained for a sufficient number of years), parental resistance, resistance from principals and other educational authorities, unresolved conflicts among teachers, lack of resources, and differing judgements about justice and fairness.
- *Cultural problems*, like views of assessment, teachers beliefs, and the "preparation ethic" (i.e., an overriding commitment to "coverage" because of a perceived need to prepare students for the next level of schooling).

Although both systemic restrictions (like, for instance, many curriculums that are more content-oriented than process-oriented, or the restricted number of hours per week in scientific disciplines) and out-of-school restrictions (like, for instance, parents objections) could play a role in the limited impact of IBL in many countries, teachers are, undoubtedly, the key actors that finally can make IBL happen in school. Knowing the obstacles and barriers they see for the use of IBL is of high importance for the professional development programme you will design and implement with teachers.

Walker (2007) has collected, from other authors, many of the problems teachers normally refer to:

- *Inquiry-based science takes more time*: this is a problem difficult to be solved. In traditional teaching, it is the teacher who is control of time. Even when experiments are included, it is quicker if the teacher explains first how to carry them out and what are the expected results. In IBL, students are not told what to do. They need time to explore the situations, to formulate their own questions, to design and carry out experiments, to build models, and so on.

- *Teacher loses control*: although it depends on the degree of freedom teacher give to students, it is clear that in IBL students should take control of the lesson. This could be in tension with teachers' beliefs about their profession.
- *Problems with safety:* especially when students are supposed to design and carry out their own experiments. General speaking, these perceptions are unfounded. Moreover, normally teachers are able to anticipate any safety problem that might occur and head them off easily.
- *Inquiry based lessons might not "work":* there is the risk that experiments do not work, that students collect wrong data and that they will get a wrong idea. In the classical use of experiments, these are carefully planned so that they always work and offer the right exemplification of the phenomena that is at stake. However, the fail of an experiment or getting wrong data should be interpreted as learning opportunity rather than a problem.
- *Lack of resources:* although some experiences require specific equipment, IBL could be implemented using in inexpensive resources. At the end, it is a matter of finding the adequate situation. Precisely, this is another concern many teachers express: where to find interesting and read-to-use examples. Nowadays, Internet offers lots of resources. There are also books and journals where teachers can find IBL situations. Moreover, teachers could adapt traditional situations to be used from an inquiry perspective.
- *Inquiry is only of value to high ability students:* this is a main concern many teachers make. If and open-ended unstructured IBL project dealing with new contents is introduced in a classroom for the first time, it is a reasonable concern that only brilliant students will find a way go through. However, when IBL is introduced gradually, different studies have showed that average and below average students can be involved in this way of learning mathematics and science, and even that results of this kind of students improve.
- *Student resistance to inquiry:* when IBL is introduced, students find a new way of working in school they are not used to. Their beliefs about their role in school are challenged, also their beliefs about teacher's role. Moreover, many of them have the feeling that they have to leave their "safe" and "quite" place: just listening and copying. In IBL situations, they have to leave their passive role and adopt a new active one. This takes effort and students might be reluctant in the beginning. But once the initial resistant is overcome, many studies have shown that students find mathematics and science more interesting, rewarding and enjoyable. On the other hand, other student related problem might be that they do not know how to do inquiry. Once again, introducing IBL gradually will help to minimize this problem. As students inquiry skills grow, more complex and unstructured situations might be used.

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- *Lack of training and support:* many teacher might argue that the do not have get sufficient support and training to conduct IBL themselves. Even if they are wishing to use the IBL approach and they are involved in some professional development, they will not get enough support from other colleagues or from their principals. For the first concern, PRIMAS will offer a long-term professional development programme that will help teachers to overcome it. For the second one, some actions could be taken, like for instance trying to involve in the PD programme as many teachers as possible from the same school.
- *Difficulty of assessment:* if assessment is based on students' factual knowledge, it might happen that students involved in IBL activities will perform worse. However, our position about IBL is that it should be intertwine with other traditional teaching methods more focused on facts and procedures. However, adopting IBL implies that traditional assessment methods should be changed, in order to assess not just facts and produces but also processes.

Some of these problems are real and difficult to deal with, whilst others are just perceived difficulties that might be overcome. However, it is important to be aware of these problems; they will probably emerge when you start working with teachers and, together with them, you will find, when possible, ways to overcome them

Besides these reasons, many teachers find that IBL comes into conflict with the way they learnt science and mathematics in school and at the university, and even with the way they have been teaching science and mathematics for many years. That is, with their beliefs about the nature of mathematics/science and/or their beliefs about the teaching of mathematics/science. Probably this will be one of major obstacle you will find. Although there is no a single and simple solution for this situation, as far as teachers are involved in IBL situations as learners, reflecting later about the way they work in them, their beliefs and attitudes start to change.

Later, when they start using IBL in their teaching, a positive balance between the efforts they have to put into place and the results they get from their students will encourage them to go on. In any case, it seems reasonable to start teachers' IBL experience gradually, although this will depend on the teacher.

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IBL pedagogies

In this section we will summarize useful pedagogies and underlying assumptions that support IBL.

## The aim

To introduce effective pedagogies that support teaching approaches in mathematics and science based on inquiry and problem solving.

## The outcome

You will learn about the kind of pedagogies you will help teachers to develop and master during their participation in the PRIMAS programme.

## Contents

- Pedagogies that support IBL

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## Pedagogies that support IBL

The Rocard-Report (2007) draws a distinction between two approaches to teaching: a deductive, teacher-centred, transmission approach in which students are the passive recipients of information, and an inductive, student-centred, collaborative approach, referred to as inquiry-based education. The prevalent lack of enthusiasm for Mathematics and Science in schools is mainly due, the report asserts, to the prevalence of transmission methods. This first description can helps us to set the scenario, but it is still rather general.

The "transmission approach" could be considered as the dominant teaching model, at least in the last decades. Even nowadays, the use of pedagogies typically associated with the "transmission approach" can be observed in many classrooms, although some changes can be perceived (as reported in the TALIS report).

Using IBL methodologies implies both a change on the roles typically ascribed to teachers and students. In a very clear and useful description, Anderson (2002) compares teacher role, student role, and student work in traditional non-inquiry-oriented teaching (*old orientation*, similar to the "transmission approach" described in the Rocard report) and inquiry-oriented approaches (*new orientation*).

| Predominance of old orientation (non inquiry-oriented) | Predominance of new orientation (inquiry-oriented) |
|---|---|
| **Teacher role:** | |
| *As dispenser of knowledge:* | *As coach and facilitator:* |
| Transmits information | Helps students process information |
| Communicates with individuals | Communicates with groups |
| Directs students actions | Coaches students actions |
| Explains conceptual relationships | Facilitates students thinking |
| Teachers knowledge is static | Models the learning process |
| Directed use of textbook, etc. | Flexible use of materials |
| **Student role:** | |
| *As passive receiver:* | *As self-directed learner:* |
| Records teacher's information | Processes information |
| Memorizes information | Interprets, explains, hypothesizes |
| Follows teacher directions | Designs own activities |
| Defers to teacher as authority | Shares authority for answers |
| **Student work:** | |
| *Teacher-prescribed activities:* | *Student-directed learning:* |
| Completes worksheets | Directs own learning |
| All students complete same tasks | Tasks vary among students |
| Teacher directs tasks | Design and direct own tasks |
| Absence of items on right | Emphasizes reasoning, solving problems, building from existing cognitive structures, and explaining complex problems |

Anderson (2002, p. 5)

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Normally, behind the teaching approach one teacher uses there is a complex set of beliefs and attitudes about the nature of the discipline (mathematics or science), about how students learn and about how teachers should better support students' learning process (Fig. 2).

| **Mathematics is:** | |
|---|---|
| Transmission: | a given body of knowledge and standard procedures. A set of universal truths and rules which need to be conveyed to learners. |
| Discovery: | a creative subject in which the teacher should take a facilitating role, allowing learners to create their own concepts and methods. |
| Connectionist: | an interconnected body of ideas which the teacher and the learner create together through discussion. |
| **Learning is:** | |
| Transmission: | an individual activity based on watching, listening and imitating until fluency is attained. |
| Discovery: | an individual activity based on practical exploration and reflection. |
| Connectionist: | an interpersonal activity in which learners are challenged and arrive at understanding through discussion. |
| **Teaching is:** | |
| Transmission: | structuring a linear curriculum for the learners; giving verbal explanations and checking that these have been understood through practice questions; correcting misunderstandings when learners fail to 'grasp' what is taught. |
| Discovery: | assessing when a learner is ready to learn; providing a stimulating environment to facilitate exploration; avoiding misunderstandings by the careful sequencing of experiences. |
| Connectionist: | a non-linear dialogue between teacher and learners in which meanings and connections are explored verbally. Misunderstandings are made explicit and worked on. |

Fig. 2. Beliefs about mathematics, teaching and learning. Swain & Swan (2005, p. 55)

Although this analysis has been made from the perspective of mathematics, connections with the nature of scientific disciplines, students science learning, and science teaching can be easily made, probably just adjusting some statements.

The model inquiry-based learning PRIMAS is aiming at should not be confused with that of 'discovery' teaching, where the teacher simply presents tasks and expects learners to explore and discover ideas for themselves. While 'discover' teaching is still inquiry-based, it appears less effective than the 'challenging', 'collaborative' teaching as outlined in Fig. 2.

In the model of IBL we want to spread through PRIMAS, teacher will have a much more pro-active role than that of a mere 'facilitator'. The teacher's role in our model will be to:

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- choose appropriate challenges for learners;
- make the purpose of activities clear;
- help learners to see how they should work together in profitable ways;
- recognise and build on learners' prior knowledge;
- encourage learners to explore and exchange ideas in an unhurried, reflective atmosphere;
- encourage the discussion of alternative methods and understandings;
- remove the 'fear of failure' by celebrating mistakes as learning opportunities rather than as problems to avoid;
- challenge learners through effective questioning;
- manage small group and whole class discussions effectively;
- draw out the important ideas in each lesson;
- help learners to make connections between their ideas.

In order to support teachers in adopting these different professional skills, PRIMAS will offer a set of professional development modules that cover many of them:

| *Module* | *Description* |
|---|---|
| Student-led inquiry | In this unit, teachers will be encouraged to experience what it feels like to think like a mathematician or scientist, and reflect on the role shifts that are necessary for students to share this experience in the classroom. Teachers are shown phenomena and situations and are invited to pose and pursue their own questions. This experience is then transferred to the classroom. |
| Tackling unstructured problems | This unit compares structured and unstructured versions of problems and considers the demands and challenges unstructured problems present to students and teachers. |
| Learning concepts through inquiry | This unit considers how the processes of inquiry based learning may be integrated into the teaching of Mathematics and Science content. |
| Asking questions that promote IBL | This unit contains a selection of professional activities that are designed to help teachers to reflect on:<br>• characteristics of their questioning that encourage students to reflect, think and reason;<br>• ways in which teachers might encourage students to provide extended, thoughtful answers, without being afraid of making mistakes; |

| | |
|---|---|
| | • the value of showing students what reasoning means by 'thinking aloud'. |
| Students working collaboratively | This unit is designed to offer the professional development provider some resources that will help teachers to:<br>• consider the characteristics of student-student discussion that benefit learning;<br>• recognise and face their own worries about introducing collaborative discussion;<br>• explore techniques for promoting effective student-student discussion;<br>• consider their own role in managing student-student discussion;<br>• plan discussion based lessons. |

Using IBL tasks in classroom is not exempt from difficulties and problems. Being aware of some of them is important. Lawson (2000), describes the main problems newly trained teachers faced in managing IBL classrooms. Some of them are:

- *Students do not participate enough*: IBL is characterized by group work, which can be problematic sometimes. The size of the group (2-3 students) is important in order to ensure that all of them are working. It is also important to carefully control time and to inform them in advance. Besides, it is crucial to assign each group member a specific tasks or role inside the group, so that all the students keep the responsibility for something. Finally, the best way of encouraging students' participation is through an effective use of questioning techniques[6].
- *Some students do not know how to get the inquiry started*: many times, this problem is connected with unclear and/or incomplete introductory instructions. It is important to be clear on the objectives and task structure before students start working (for instance, explore the materials and pose three questions; generate al least three hypotheses, design and conduct test of one of these hypothesis; graph data and post it on the board). Additionally, Walker (2007) points out that students are more likely to find problems at the beginning (when they have to find a problem, and develop questions and hypothesis). If this is too difficult for them, teacher could provide information or prompt them to find what they need so the can go on. Besides, many students will be reluctant to start inquiring and will ask just the teacher to give them the answer. This resistance is normal, as IBL is more challenging for them that just listening. However, as they are getting use to inquiry, students find it more interesting and motivating than traditional teaching practices.

[6] In the PRIMAS professional development resources you will find a module dealing with effective questioning.

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- *Some students do not care and do not see the inquiry as relevant to their lives*: although it is teacher's decision to choose one IBL activity or other, it is clear that many of the questions raised by the inquiries could be not directly relevant to students' lives. However, normally the concepts embedded in answering the questions are indirectly relevant for them. Moreover, despite the more or less interest in the topic inquired, most of the students like inquiries, especially those that raise challenging enough but not overwhelming questions.
- *Some students lack background knowledge for inquiries*: on the one hand, a careful planning and an a-priori analysis of the IBL activity could reduce this problem. On the other hand, sometimes will be necessary to introduce some background knowledge at the beginning.
- *Some students have bad attitudes and are disruptive***:** once again, this is a general problem, not only restricted to IBL-oriented classrooms. One possible reason for this kind of students' behaviour might be an inadequate selection of the inquiries, too challenging or not challenging enough.
- *Some students do no want to think for themselves – they just want to be told the right answers*: IBL is more demanding for students than traditional teaching. IBL implies a change in students' job: from listening and reciting "correct answers" to getting actively involved in inquiry processes (posing questions, formulating hypothesis…). Assessment plays here a crucial role: use tests and exams that include thought-provoking items, and not just knowledge-recalling. Generally, after the initial resistance, most of the students find IBL more interesting and motivating that lecturing.
- *Some students do not listen, are bored or disruptive*: this is not a problem only in IBL activities. Try to reduce the time you take for introductory remarks and use it effectively. Once students have been engaged in an exploratory activity, it is easier to catch their attention, as discussion will be then centered on their own experiences. The key is to let students do something first and talk about it later. Besides, students will become bored and disruptive if they find the work they are doing too easy or too difficult.  Try to tailor tasks for students of different abilities. Finally, as said before, the management of time is crucial. If there is not a clear structures of time frames for their work, many students will be ineffective in managing their own working time and will waste it, becoming thus bored or disruptive.

From the analysis of these problems, Lawson (2000) propose a list of teaching tips for managing the inquiry in classroom:

- Keep working group as small as possible.
- Tell students about how much time they have to complete each task
- Plan more activities than you will have time for.
- Monitor student progress

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- Plan key questions to raise an plan how/when to raise them
- Randomly call on students to respond
- Use Wait-Times I (after you formulate a question) and II (after students give an answer).
- Accept all sincere student responses
- Keep your introductory remarks clear and concise
- Hold a class discussion when groups are struggling
- Point out relevant concept applications
- Phrase questions clearly
- Remind students of the importance of the reasoning patterns involved in inquiry
- Hold discussions *after* exploration activities
- Sequence instructions so that later inquiries serve as concept applications
- Use your introductory remarks to provide key background knowledge
- Raise a well phrased divergent question to initiate student hypothesis generation
- Do not allow hypotheses to be critiqued until all have been generated
- Generate some hypothesis yourself
- When necessary, provide time for small group discussion
- Do not tell students which hypotheses are "correct"
- Make sure that the materials allow for a variety of tasks of varying difficulty levels
- Use a pretest to alert you to varying levels of student reasoning skill
- Mix reasoning skill levels to from effective working groups
- Make sure that quizzes and exams require thinking
- Use essay questions and/or alternate test forms

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PROMOTING INQUIRY IN MATHEMATICS AND SCIENCE EDUCATION ACROSS EUROPE

Professional development

In this section, important information about how teachers change and growth happens, about effective professional development, and strategies for professional development will be introduced.

## The aim

To offer a clear and deep vision how teachers as professionals learn and how best can you support this process.

## The outcome

You will learn about teachers' growing process, about what makes a PD programme effective and about different PD strategies.

## Contents

- How do teachers grow? A model for teachers' professional development.
- How can I contribute to success? Effective professional development.
- How can I support teachers' growth? Professional development strategies

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## How do teachers grow? A model for teachers' professional development

It is not the aim of this section to carry out a deep analysis about how teachers learn and how they make their, knowledge, practices, beliefs, and attitudes evolve. We will address some important issues that synthesises our view of teachers' professional development. The next sections will be based on this model.

### *What is teachers' knowledge made of?*

A well-known and commonly accepted description of teachers' knowledge is that provided by Shulman (1986). He distinguishes between:

- *Teachers' content knowledge* (CK): knowledge about the discipline or disciplines teachers have to teach (mathematics, biology, physics, chemistry…)
- *Teachers' pedagogical knowledge* (PK): general pedagogical content shared between different subjects.
- *Teachers' pedagogical content knowledge* (PCK): it is in the intersection between CK and PK. It can be seen as a kind of specialized subject-dependent knowledge teachers need in order to effectively help students to learn mathematics or scientific knowledge.

PCK includes, for a specific school subject:

- The ways of representing and formulating the subject that makes it comprehensible to others (representations, analogies, illustrations, examples, explanations…).
- An understanding of what make the learning of specific topics easy or difficult (conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of these topics).

In the same vein, Joubert & Sutherland (2009) refer to a general agreement in the literature about three aspects of knowledge teachers need:

- Knowledge about mathematics/sciences.
- Knowledge about students' mathematical/scientific conceptions
- Knowledge about ways of teaching mathematics/science

But teachers' professional knowledge includes not only these three types of knowledge, but also beliefs about the nature of the discipline they teach, about how students learn, about teaching and, more generally, about their profession.

Teachers' knowledge, beliefs and attitudes are the key elements to understand the way teachers act in the classroom. But all these elements are not static or fixed. On the

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contrary, some of them are continually evolving and changing, and this evolution can be mediated by different circumstances like, for instance:

- Teachers' reflection about their practice
- Teachers' interaction with other colleagues
- Papers, books, web pages and other materials teachers' read
- Teachers' participation in workshops and courses
- Teachers' engagement in professional development programmes

That is why it is usual to talk about "teacher growth". It is a metaphor that directly reflects this changing nature of teachers' knowledge, beliefs and attitudes. It is a way to stress the progression teachers experience as their knowledge, beliefs and attitudes are changing and evolving.

It is also worth to mention the distinction Eraut (2007) draws between teachers' *cultural* and *personal knowledge*:

- *Cultural knowledge* is made of codified academic knowledge and the know-how of the profession (which is not necessarily codified).
- *Personal knowledge* is the knowledge that a person brings to a situation that enables them to act and practice in the situation. It can include knowledge, know-how (skills and practices), understandings of peoples and situations, accumulated memories, practical wisdom and self-knowledge, attitudes, values and emotions (Joubert and Sutherland, 2009)

The ways teachers perform in the classroom as well as the decisions they make are informed by both their personal and cultural knowledge.

Loucks-Horsley et al. (2003) summarize quite well the nature of teachers' knowledge and its on-going evolution:

> "*like other professions, teachers expect to continue learning throughout their careers to deepen their expertise and enhance their practice. They recognize that they practice in uncertain circumstances, that much of their knowledge is embedded in their practice rather than in codified bodies of knowledge, and that their extensive, complex knowledge, particularly with respect to their understanding of how learners learn, profoundly influences how they teach*" (ibid, p. 40).

***A model of teachers' professional growth***

Many authors have been studing how teachers' professional changing and growth happens. We will summarize some useful information here, that will help you to monitor and enhance the changing and growing process of the teachers you will be working with.

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Any professional development programme aims to make evolve teachers' classroom practices, and teachers' beliefs and attitudes evolve; also to improve students' learning outcomes. Different authors have studied the sequence in which these changes might occur.

First of all, what is the meaning behind the words "teacher change"? Clark et al. (2002) summarizes some of these meanings, which are not mutually exclusive. We reproduce it here literally:

- *Change as training* – change is something that is done to teachers; that is, teachers are "changed".
- *Change as adaptation* – teachers "change" in response to something; they adapt their practices to changed conditions.
- *Change as personal development* – teachers "seek to change" in an attempt to improve their performance or develop additional skills or strategies.
- *Change as local reform* – teachers "change something" for reasons of personal growth.
- *Change as systemic restructuring* – teachers enact the ''change policies'' of the system.
- *Change as growth or leaning* - teachers ''change inevitably through professional activity''; teachers are themselves learners who work in a learning community.

Historically, teacher change has been directly linked with planned PD activities, which attempt to qualify teachers with those skills they lack, often through direct training. Nowadays, teachers are seen as life-long professional learners, which growth can be explained more in terms of looking for a greater fulfilment as practitioners than repairing "personal inadequacies". And this have an impact in the way PD programmes are conceived: from PD programmes that aims to change teachers, to teachers as active learners shaping their professional growth through reflective participation in PD programmes and practice (Clark et al. 2002, p. 948).

Other authors, like Guskey (2002), consider that there are two crucial factors to be considered when designing and implementing PD:

- What motivates teachers to engage in professional development.
- The process by which change in teachers typically occurs.

Concerning the first factor, he argues that there are two main reasons that motivate teachers to engage in PD programmes:

- One is certification or contractual agreements.
- The other one is because they want to enhance students' learning outcomes.

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When asked, most of the teachers refer to the second reason: they expect that the PD programme will expand their knowledge and skills, contribute to their growth, and enhance their effectiveness with students (ibid, 382).

However, at the same time, teachers tend to be quite pragmatic: as the result of their engagement in a PD programme, most of them want to acquire specific, concrete, and practical ideas that directly relate to the day-to day teaching practice.

***Recommendation****: PD programmes that fail to address these needs are unlikely to succeed (Guskey, 2002, p. 382).*

In relation with the second factor (how does teachers change typically occurs), the author argues that many PD programmes fail because they focus first and mainly on changing teachers' beliefs and attitudes. The logic behind this choice (see Fig. 3) is that changes in beliefs and attitudes will lead to specific changes in teachers' classroom behaviours and practices, which in turn will result in improved student learning (ibid, p. 382).

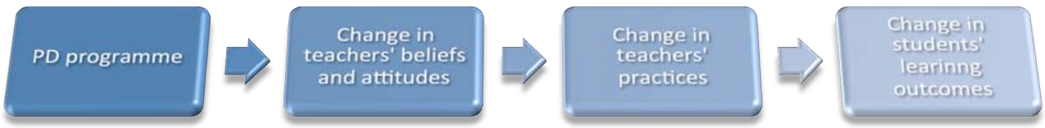
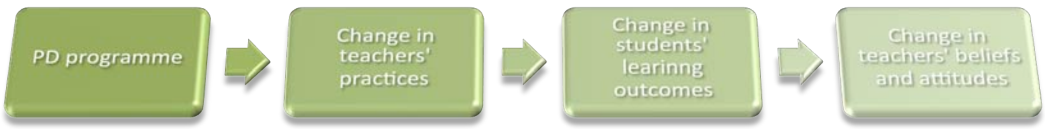



Fig. 3. Teacher's change (based on Guskey, 2002)

Professional development programmes assuming this model of teachers' growth are typically designed to gain teachers' acceptance, commitment, and enthusiasm from teachers before the implementation of new practices or strategies (Guskey, 2002, p. 383).

In contrast to this model, the author argues for a different one, which underline assumption is that it is the change in teachers' practice that leads to an improvement on students' learning outcomes[7] that finally will provoke a change on teachers' beliefs and attitudes (see Fig. 4). In other words, "it is not professional development, *per se,* but the experience of successful implementation that changes teachers' attitudes and beliefs. They believe it works because they have seen it work;
and that experience shapes their attitudes and beliefs" (Guskey, 2002, p. 383).




[7] The author considers "students' learning outcomes" in a broadly way, including not only cognitive achievements but also a wide range of student behaviour and attitudes (e.g., students' scores on teacher-made examinations, students' attendance, their involvement in class sessions, their classroom behaviour, their motivation for learning, or their attitudes towards school and towards the subject they are learning…).

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Fig. 4. Teacher's change (based on Guskey, 2002)

From these reflexions, Guskey (2002) extracts three main recommendations for designing professional development:

**Recommendations**:

1. *Recognize that change is a gradual and difficult process for teachers*. Adopting new methodologies and pedagogical approaches (like those associated with IBL) requires time, effort, and an increased workload. No change happens uniformly or in a single step.
2. *Ensure that teachers receive regular feedback on student learning progress*.
3. *Provide continued follow-up, support and pressure,* because, even with a high-quality initial training, change will occur mainly after implementation takes place and evidence of improved students' learning outcomes is perceived.

However, both models (Fig. 3 and 4) could be criticised in that they conceptualize teachers' growth as a linear process. That is why other authors, like Clark et al. (2002), propose an interconnected model (Fig. 5) of teacher change, which suggests that change occurs through the mediating process of "reflection" and "enactment", in four distinct domains that encompass the teacher's world: the *personal domain* (teacher knowledge, beliefs and attitudes), the *domain of practice* (professional experimentation[8]), the *domain of consequence* (salient outcomes), and the *external domain* (sources of information, stimulus or support) (ibid, p. 950).

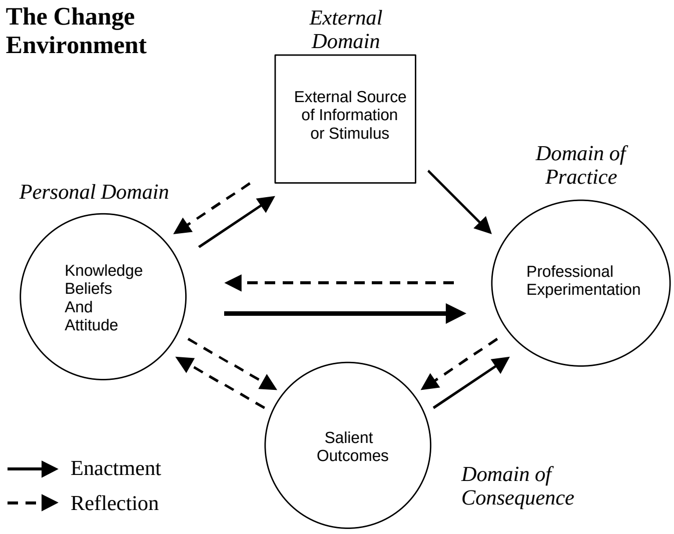


Fig. 5 (Clark et al., 2002, p. 951)

[8] Which includes all forms of professional experimentation, apart from experimentation within the classroom.



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As explained by the authors, the model identifies that it is through “enactment” and “reflection” that changes in one domain lead to changes in another domain. The term “enactment” was chosen to distinguish the translation of a belief (*personal domain*) or a pedagogical model (*external domain*) into action (*domain of practice*) from a simply “acting”.

Without going into further details, this model synthesises the complex nature of teachers’ professional growth and give you, as responsible of P
RIMAS CPD programme and facilitator of teachers’ development, a valuable tool to sequence and monitor the growing process of the teachers you will work with.

Finally, we will refer to the work of Loucks-Horsley et al. (2003). From a review of several research papers, they summarize some key features of the change process:

- Change is a process that takes time and persistence.
- At different moments in the change process, individuals need different kinds of support and assistance.
- Change efforts are effective when the change to be made is clearly defined and communicated, support and assistance are available, and leaders and policies support the change.
- Most systems resist to change.
- Organizations that are continuously improving analyse data, set goals, take actions, assess their results, and make adjustments.
- Change requires communication about complex topics in organizations that are, for the most part, large and structured.

***Models of Continuing Professional Development***

In this subsection some general information about how continuing professional development (CPD) could be modelled and structured will be introduced. PRIMAS CPD programme will be built in relation to some of these models. Moreover, this information will be useful when you design and implement your local adaptation of PRIMAS CPD.

Kennedy (2005) draws a rich picture of different models of CPD. We will summarize these models, including some feature of each one. The criterion she uses to categorize CPD is that of the perceived purpose of each model. She identifies 9 models of CPD, organized in terms of the potential capacity to transform teachers’ practice and professional autonomy. Besides, she explores the circumstances in which each model might be adopted and explores the form(s) of knowledge that can be developed through each particular model. The next descriptions of each model have been taken from Kennedy’s paper:

- *The training model*: this model supports a technocratic view of teaching and a view of CPD as a way of updating teachers’ teaching skills. It is usually “delivered” to

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teachers by an expert, with the agenda determined by the deliverer; participants are normally placed in a passive role. Normally, it is criticised because of its lack of connection to the current classroom context in which participants work. Despite its drawbacks, the training model is acknowledged as an effective means of introducing new knowledge.

- *The award-bearing model*: this model relies on, or emphasises, the completion of award-bearing programmes of study – usually, but not exclusively, validated by universities.
- *The deficit model*: in this model, PD is designed specifically to address a perceived deficit in teacher performance.
- *The cascade model*: this involves individual teachers attending 'training events' and then cascading or disseminating the information to colleagues. It is commonly employed in situations where resources are limited. Several authors argue that this model supports a technicist view of teaching, where skills and knowledge are given priority over attitudes and values, whilst it neglects the context in which these skill and knowledge are gained or used.
- *The standards-based model*: this model aims to develop teachers' professional abilities in line with the ones described in existing educational standards. This model belittles the notion of teaching as a complex, context-specific, political and moral endeavour. Some justifications for this model are that it could be used to scaffold professional development and that it could provide a common language, which will enable greater dialogue between teachers. As a disadvantage, the potential of standards to narrow conceptions of teaching or, indeed, to render it unnecessary for teachers to consider alternative conceptions outwith those promoted by the standards.
- *The coaching/mentoring model*: the defining characteristic of this model is the importance of the one-to-one relationship, generally between two teachers, which is designed to support CPD. Both coaching and mentoring share this characteristic, although most attempts to distinguish between the two suggest that coaching is more skills based and mentoring involves an element of "counselling and professional friendship". Key to his model is that professional learning can take place within the school context and can be enhanced by sharing dialogue with colleagues. Depending on the matching of those involved in the coaching/mentoring relationship, this model can support either a transmission view of professional development or a transformative view, where the relationship provides a supportive but challenging forum for both intellectual and affective interrogation of practice. In order for the coaching/mentoring model of CPD to be successful, participants must have well-developed interpersonal communication skills.
- *The community of practice model*: this model is based on an social theory of learning (Wenger, 1998), recognizing that learning within a community of practice

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happens as a results of that community and its interactions, and not merely as a result of planned learning episodes such as courses. Although there is a clear relationship with the coaching/mentoring model, now there are more than two people involved and it does not have to be organized hierarchically. Within a community of practice, learning could be either a positive and proactive or a passive experience, where the collective wisdom of dominant members of the group shapes other individuals' understanding of the community and its roles. In any case, in order to internalize learning, it is crucial the awareness of the members about the existence of the community. For the successful of CPD within a community of practice, the issue of power is fundamental. A community of practice should create its own understanding of the joint enterprise, therefore allowing the members of that community to exert a certain level of control over the agenda. Although it has been argued that communities of practice can potentially serve to perpetuate dominant discourses in an uncritical manner, under certain conditions they can also act as powerful sites of transformation, where the sum total of individual knowledge and experience is enhanced significantly through collective endeavour.

- *The action research model*: action research can be defined[9] as a "systematic, reflective study of one's actions, and the effects of these actions, in a workplace context". Advocates of the action research model tend to suggest that it has a greater impact on practice when it is shared in communities of practice or enquiry, and indeed, many communities of practice will engage in action research (although this is not a prerequisite). Action research model provides an alternative to the more passive traditional models; teachers are encouraged to view research as a process and not just as a product. Action research model of CPD has been acknowledged as being successful in allowing teachers to ask critical questions of their practice. Therefore, it has a significant capacity for transformative practice and professional autonomy.
- *The transformative model*: this model of PD involves the combination of a number of processes and conditions – aspects of which are drawn from other models outlined above. The central characteristic is the combination of practices and conditions that support a transformative agenda. In this sense, it could be argued that the transformative model is not a clearly definable model in itself; rather it recognises the range of different conditions required for transformative practice.

The next table, extracted from Kennedy (2005) summarizes the transformative nature of each model and the teachers' autonomy they allow:

[9] Definition taken from http://cadres.pepperdine.edu/ccar/

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| Model of CPD | Purpose of model | |
|---|---|---|
| The training model<br>The award-bearing model<br>The deficit model<br>The cascade model | Transmission | |
| The standards-based model<br>The coaching/mentoring model<br>The community of practice model | Transitional | Increasing capacity for professional autonomy |
| The action research model<br>The transformative model | Transformative | |

Kennedy (2005, p. 248)

Although you, as the maximum responsible for the organization of PRIMAS CPD, will have the freedom and the responsibility to choose between some of these models, PRIMAS philosophy about teachers' professional development will be more in the line of the transformative models, without denying that some transmission might be needed in the initial stages of the program and that transitional models could be considered to be useful until teachers' confidence, beliefs and knowledge have grown enough.

In this point, it is worth to summarize the difference between teachers' "additive" versus "transformative" learning, as it is described by Loucks-Horsley et al. (2003):

- Teachers' "additive" learning: they develop new skills or learn new things to integrate with what they currently know (Thompson and Zeuli, 1999)
- Teachers "transformative" learning: they are engaged in strategies that produce changes in deeply held beliefs, knowledge, and habit of practice.

Professional development programmes that offer new skills and knowledge to teachers, but fail in helping them to rethink and transform their beliefs and their practices, might be considered as "additive" programmes. We know from research that these programmes have little impact on teachers' behaviours and beliefs beyond the programme itself and that most of them fall into obscurity.

## How can I contribute to the success? Effective professional development

Many research studies have explored what are the features for a professional development programme to be effective. Although this is more complex than writing a list, and contextual factors can be absolutely crucial for the successful of a PD programme, it is worth to summarize these findings in order to orientate your work when designing and implementing your PRIMAS CPD programme.

SEVENTH FRAMEWORK PROGRAMME

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First, we will refer to the findings of the English project RECME[10]. After the review and study of thirty CPD programmes in England for mathematics teachers and asking teachers that participated in them, RECME offers a list of factors that contribute to effective CPD for teachers of mathematics. Most of the results could be extended for science teacher CPD as well[11]. In the next excerpt, some of their findings are reproduced:

- *Leadership*: Leadership of the CPD was identified by teachers as of key importance and they especially valued leaders with wide knowledge and understanding of current practice.
- *A practical approach*: Teachers valued practical advice that was directly applicable to the classroom, including resources and banks of resources that they could use with minimal adaptation. In many cases they valued having attention drawn to the use of practical equipment and ICT resources which support mathematical thinking and reasoning. They appreciated CPD that was grounded in classroom practice.
- *Stimulation, challenge and enjoyment*: Teachers valued CPD that was stimulating, enjoyable and challenging. Challenge within CPD was not a comfortable experience for some teachers; appropriate support from the CPD initiative was often provided.
- *Time*: Time was mentioned as a big issue for most participants and they valued the time that their involvement in the CPD initiative gave them to focus on their professional practice. This often involved release from the classroom, standing back from their day-to-day practice and reflecting on their practice.
- *Networking*: The opportunities for networking with colleagues from the same or different schools that involvement in CPD gave the teachers were highly valued. Teachers valued meeting colleagues with very similar work settings as well as appreciating opportunities to work with teachers from other phases or settings. They also emphasised the value of the incidental conversations that took place within CPD sessions.
- *Area of focus* (mathematics): In CPD for teachers of mathematics, it seems to be important to pay attention to mathematics, to ways of teaching the subject and to students' mathematical conceptions. Many teachers seemed to enjoy doing mathematics and thinking about connections within it. Engaging in mathematical activities may have encouraged teachers to consider what it feels like to be a student, hence making them more sympathetic to students' needs.
- *Students' learning of mathematics*: CPD initiatives that engaged in cycles of planning teaching and predicting student responses to particular mathematical activities, followed by teaching and reflecting on the actual student responses, seemed to provide teachers with ways in which to talk about student learning.

[10] Researching Effective CPD in Mathematics Education. The whole report can be retrieved from the site of the National Centre for Excellence in the Teaching of Mathematics (https://www.ncetm.org.uk/enquiry/9251 )
[11] Although no CPD programme for science teacher was analysed in RECME.

- *Encouraging reflection*: Initiatives that encouraged teachers to become more reflective often engaged them with research and professional literature related to teaching and learning mathematics. It seems that it is important to provide teachers with opportunities to read and think about ideas from research.
- *Expecting and supporting change*: Where CPD initiatives wanted teachers to try out new ideas in the classroom, it seems that different approaches to encouraging them were effective. In some, there was a clear expectation on the part of the course leader that teachers would try out new ideas in the classroom, and this expectation appears to have provided the motivation to change. In addition, in some initiatives there was some pressure to report back to the group and/or to write reflective diaries, which may have provoked teachers to make changes. In other initiatives, considerable in-school support was provided for teachers to try out new ideas in the classroom.
- *Supporting the embedding of change*: In initiatives that were set up to help teachers embed change, discussion at CPD meetings of the approaches teachers were taking in the classroom seemed to reassure them and encourage them to continue using these approaches. At these meetings, the teachers also worked together to develop new ideas and resources to support them in embedding changed practices.

Second, we will refer to the work of Loucks-Horsley et al. (2003). They summarize several principles they found present in quality PD experienced they analysed

- Effective PD experiences are driven by a well-defined image of effective classroom learning and teaching.
- Effective PD experiences provide opportunities for teachers to build their content and pedagogical content knowledge and skills and examine practice critically.
- Effective PD experiences are research based and engage teachers as adult learners in the learning approaches they will use with their students.
- Effective PD provides opportunities for teachers to work with colleagues and other experts in learning communities to improve their practice.
- Effective PD experiences provide links to other parts of the education system.
- Effective PD experiences are designed based on data that determine their focus and priority as they relate to students' learning, and they are continuously evaluated to ensure a positive impact on teacher effectiveness, student learning, leadership, and the school community.

SEVENTH FRAMEWORK PROGRAMME

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## How can I support teachers' growth? Professional development strategies

Very often, teachers' professional development is identified with training courses in which teachers are supposed to learn new content knowledge/teaching methods, and/or their beliefs and attitudes are challenged in an attempt to make them evolve.

It is not our aim to deny that training courses might be a component of professional development. But, once we know how teachers learn and grow, it is clear that other kind of professional development strategies should be considered in order to engage teachers in a rich variety of experiences they will need to make their knowledge, practices, beliefs and attitudes evolve.

Following Loucks-Horsley et al. (2003), we will introduce a palette of professional development strategies you might consider to use when designing and implementing PRIMAS in your country.

The aim of introducing all this strategies is to offer you a wide variety of ways to organize PRIMAS. Finally you will have to choose among them in order to fit into your national conditions and restrictions.

There are not good or bad strategies. Each one potentially has positive and negative aspects. They are not independent or exclusive. It depends on the goals of your PD programme. For instance, if the aim is to develop teachers' content knowledge and pedagogical content knowledge, then case discussions, immersion experiences, workshops, or partnership with scientists and mathematicians could be considered as good strategies. But if the aim is to help teachers to "translate" new knowledge into practice, then coaching, mentoring, curriculum implementation, or demonstration lesson seems to fit better (Loucks-Horsley et al., 2003, p. 115).

We will reproduce, most of the times literally, a brief explanation, the key features of each one, and the implementation requirements. We kindly encourage you to go to the original source[12] for a complete and original description of these strategies, and to find interesting examples.

***Curriculum alignment and materials selection***

Brief description:

- Thoughtful analysis of the curriculum and its alignment with local and national standards. It could include various activities to increase teachers' knowledge (e.g.,

[12] Loucks-Horsley, S., Love, N., Stiles, K., Mundry, S., and Hewson, P. (2003). *Designing profesional development for teachers of science and mathematics*. Thousand Oaks, California: Corwin Press, Inc.



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studying standards to identify the meaning and intended students' goals, developing a common vision of standards-based teaching and learning, identifying local needs based on student learning and other data, or selecting materials, pilot testing them, and developing a plan for implementation).

Key elements:

- Teachers are essential participants in the process of aligning curriculum, selecting instructional materials, and implementing those materials.
- Teachers undertake a process of examining curriculum and instructional materials that leads to a new product and learning.
- Aligning curriculum and selecting instructional materials require a clearly articulated procedure that addresses all aspects of the process.
- Curriculum alignment and instructional materials selection is a collaborative activity.

Implementation requirements:

- District or school administrative support, encouraging the process, providing time and incentives for teachers, ensuring access to resources and experts, and supporting on-going, long-term improvement of the curriculum and instructional materials that are ultimately implemented.
- Process for selection including rubrics, tools, and forms for tracking what was piloted and its results.

***Curriculum implementation***

Brief description:

- The implementation of new curricula in classroom can serve as a powerful learning experience for teachers.
- Through using curriculum in their classrooms, reporting on what happens, and reflecting with others on the strengths and weaknesses of different ideas and activities, teachers learn about their own teaching and their students' learning.
- Teachers' time is devoted to teach the new curriculum, learning how to conduct the activities, learning how students learn the new material, and incorporating the new curriculum into their long-term instruction.
- The goal is not only to implement the new curriculum, but also to strengthen teachers' knowledge about the content and pedagogy in the curriculum.

Key elements:

- Quality curriculum materials that are based on standards.
- Teachers learn about the curriculum by teaching it and reflecting on it.
- Planning and support for the implementation are critical.

Implementation requirements:

- Time (to learn about the new curriculum, to try it in their classrooms, to reflect with colleagues on their experiences and those of their students).

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- Teacher development opportunities (to become aware about the new curriculum, to learn to mange materials in the classroom, to learn any new science or mathematics content, to teach the new curriculum, to assess both their own and their students' learning).
- On-going commitment and support.
- Mechanisms for assessment and evaluation (to critique and process what and how they are teaching; to assess the extent of implementation and the interim results from the new curriculum).

***Partnership with scientists and mathematicians***

Brief description:

- The kind of partnership introduced here is that focused on teachers and scientist and mathematicians serving as mentors.
- Teachers and science and mathematics faculty working side by side to improve teaching strategies.
- This could include involving scientists and mathematicians in school-based activities, such as participating in the design and evaluation of curriculum materials, or sitting at the table during strategic planning and decision-making.

Key elements:

- Partners are equal (to be effective, partnership must truly be two-way exchange of resources and knowledge).
- Roles for scientist and mathematicians are clearly defined (e.g., scientists and mathematicians might help teachers to build confidence in teaching science and mathematics by modelling inquiry and providing them with new insights and experiences; exploring inquiry-based or problem-solving activities with teachers to increase their content knowledge; evaluating the scientific and mathematical accuracy of teaching materials; inviting teachers into research labs for special seminars and demonstrations; etc.).
- Consistent values, goals, and objectives are shared by all partners.
- There are benefits to teachers.
- There are benefits to scientist and mathematicians.

Implementation requirements:

- Realistic expectations.
- Orientation ad knowledge building (as far as the worlds of scientists and mathematicians differs dramatically from that of teachers, a mutual understanding of both worlds is essential. It is necessary that each one value the knowledge and expertise of the other, recognize the importance of the roles play by each person, and begin to learn about each other's work).
- Involvement (both partners must break their traditional roles and relationships – scientists/mathematicians as knowledge producers, teachers as translators of knowledge – and develop new ones).
- Commitment.



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- Leadership (because partnership often feel above and beyond the call of duty to participants who already have a full work life, the motivating force of a leader (or leaders) is vital. Good leadership keeps activities moving).

***Professional networks***

Brief description:

- A network is an organized professional community that has a common theme or purpose. Individuals join networks to share their own knowledge and experience with other network members and learn from other network participants.
- In education, these communities are often organized to improve teaching of a particular subject matter, to address pedagogy for teaching certain content or grade-level students, or in support of particular school reforms.
- Networks often articulate specific goals and purposes, recruit their members, and have schedule activities (such as summer institutes, regular meetings, electronic discussions, newsletters or chat rooms).
- Not all networks are structured formally; informal networks can also provide opportunities for exchanging information and obtaining professional support.

Key elements:

- Interactions among members are on-going (networks are “discourse communities” that enable teachers to meet regularly – either in person or electronically – to solve problems, consider new ideas, evaluate alternatives, or reflect on specific issues in science and mathematics).
- Membership is voluntary (networks maintain an atmosphere of openness and sharing that helps fellow members to see each other as problem solvers).
- Effective communication is essential (the more varied the interactions, the more likely the participants are to remain involved and committed to the efforts).
- Members’ perspectives are broadened (through interactions in the network, teachers gain new knowledge and access to research- based resources beyond their school or districts. Effective networks promote sharing of information and ideas and help teachers broaden their perspective of and exposure to issues).
- Facilitation and leadership are necessary.

Implementation requirements:

- Clear focus of activity (networks need a purpose; participants need to know why they are joining and what they can expect from their invest of time).
- Size and logistic requirements (although some electronic networks may be able to handle large numbers of participants, networks that rely on in-person interactions and prompting from a trained facilitator must be a reasonable size to allow for adequate interaction among all participants).
- Communication mechanisms (networks must have effective mechanisms for promoting communication).
- Monitoring progress and impact (effective networks pay attention to how they meet the needs of members and how they can improve).

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***Study groups***

Brief description:

- Study groups are collegial, collaborative groups of problem solvers who convene to mutually examine issues of teaching and learning.
- They are conducted within a safe, non judgmental environment in which all participants engage in reflection and learning and develop common language and vision of science and mathematics education.
- Study groups are not teachers gathering for informal, social, or unstructured discussion. Rather, study groups vary from current issues in mathematics and science education to whole-school reform.
- Regardless the topic or issue being addressed, study groups provide a forum in which teachers can be inquirers and ask questions that matter to them, and are based on improving student learning, over a period of time, and in a collaborative and supportive environment.

Key elements:

- Study groups are organized around a specific topic or issue of importance to the participants.
- Study groups have varied structures. Makibbin and Sprague (1991) suggest four models for structuring study groups:
    - *The implementation model* is designed to support teachers' implementation of strategies recently learned in workshops or other short-term sessions. The goal is to provide teachers with an on-going system for discussing, reflecting on, and analysing their implementation of strategies after the workshop has concluded.
    - *The institutionalization model* is used once teachers have already implemented new practices in the classroom and want to continue refining and improving these practices.
    - *Research-sharing groups* are organized around discussions of recent research and how it relates to classroom practice.
    - *Investigation study groups* are a way for teachers to identify a topic or practice about which they would like to learn. Teachers read about, discuss, and implement new strategies that are relevant in their own contexts – their teaching practices and their students' learning.
- Self-direction and self-governance contribute to the success of study groups.

Implementation requirements:

- Time (like most other strategies for PD, participating in a study group requires time not only to meet and address the issues but also to do so over long period).
- Support from administrators.
- Membership and substantive topics (teachers forming study groups must identify their members and identify the topic or issue that is complex and substantive enough to hold the group together).
- Study group activities (study groups use a variety of activities, including reading, examining school data, viewing videotapes, and discussing research; learning about

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new teaching and learning approaches through reading, attending workshops or other sessions, or inviting experts to work with the group; and implementing new practices in their classrooms and using the study group tie to reflect on an analyse the experience both for themselves and their students. In fact, many of the other professional development strategies described here are often combined with study groups).

- Group interaction skills (as with other strategies organized around cooperative group work, group interaction skills are critical).

***Action research***

Brief description:

- On-going process of systematic study in which teachers examine their own teaching and students' learning through descriptive reporting, purposeful conversation, collegial sharing, and critical reflection for the purpose of improving classroom practice.
- Through action-research, teachers reflect on their practices and student results by studying teaching and learning.
- The strength of action research as a PD strategy is that teachers either define the research questions or contribute to their definition in a meaningful way. Therefore, they have ownership over the process and are committed to promoting changes in practice indicated by the findings.
- Action research supports teachers to examine their teaching practices in a systematic, ongoing way with the purpose of changing those practices.

Key elements:

- Teachers contribute to or formulate their own questions, and collect the data to answer these questions
- Teachers use an action research cycle (planning, acting, observing, and reflecting).
- Teachers are linked with sources of knowledge and stimulation from outside their schools
- Teachers work collaboratively
- Learning from research is documented and shared

Implementation requirements:

- Access to research resources (initially, teachers might need someone experienced on research or a consultant to assist them)
- Time
- Administrative support and an atmosphere conducive to experimentation
- Opportunities to share the results of their research (in-house publications, professional conferences, workshops, journals…).

***Case discussion***

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Brief description:

- Case discussions offer groups of teachers the opportunity to reflect on teaching and learning by examining narrative stories or videotapes that depict school, classroom, teaching, or learning situations.
- Cases are narratives (whether in print form or on videotape) that offer a picture of a teaching or learning event and are specifically designed to provoke discussion and reflection.
- Case discussions share common goals: to increase and enrich teachers' fundamental beliefs and understanding about teaching and learning; to provide opportunities for teachers to become involved in critical discussions of actual teaching situations; and to encourage teachers to become problem solvers who pose questions, explore multiple perspectives, and examine alternative solutions.
- Not only is participating in case discussion a powerful PD strategy, but also the process of writing and developing cases enhances teachers' growth and development. The act of writing cases and then discussing them with colleagues helps teachers analyse their own instructional practice

Key elements:

- Case materials present a focused view of a specific aspects of teaching or learning (by using cases, all participants are examining the same experience and have the immediate opportunity to reflect on those experiences during the case discussion).
- Case materials illustrate theory in practice.
- Case materials provide images of reform-oriented mathematics and science teaching and learning (in the case of PRIMAS, this might be IBL lessons. Translating ways of teaching and learning into practice is often the most complex and challenging task for teachers).
- Teachers interact and learn through discussion (they formulate ideas, learn from each other, become aware of alternative strategies and perspectives, internalize theory, critique their own and others' ideas, become aware of their own assumptions and beliefs, increase their pedagogical content knowledge, and engage in collaborative reflection).
- Cases are facilitated by a knowledgeable and experienced facilitator who promotes reflection by case discussants.
- Case discussions necessarily involve effective group dynamics.
- The cases are relevant and recognizable (although some cases depict teaching or learning situations that reflect the "ideal image" of what teaching and learning can look like, teachers need, at least initially, to be able to identify aspects of their own teaching within the case).

Implementation requirements:

- Attitudes of participants and facilitators (commitment to improve their teaching practice, willingness to share and critically discuss aspects of practice, curiosity about the underling teaching and learning assumptions).

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- Skills of facilitators (understanding the science or mathematics being taught in the case, skills and experience to manage discussions).
- Time
- Access to quality cases (cases must be clear, thorough, and well developed).

***Examining students' work and thinking and scoring assessments***

Brief description:

- As teachers and entire faculties turn to examining student work as a means of enhancing their own and their students' learning, collaborative learning communities are developing and teachers are becoming more reflective of their practice.

Key elements:

- Teachers confront real problems that they face in their classrooms on a daily basis.
- This strategy engages teachers in examining what they have plenty of: student work (it might include written responses, drawings, graphs, journals, portfolios, or videotapes of interviews with students, but also written work from several students in response to the same assignment; several pieces of work from one student in response to different assignments; several pieces of work from on student in response to different assignments; one piece of work from a student who completed the assignment successfully and one piece from a student who was no able to complete the assignment successfully; work done by students working in groups; or videotape, audiotape, or photographs of students working, performing, or presenting their work).
- This strategy provides a focused goal and purpose for the discussions and examination of student work.
- Teachers' learning is a result of the shared, collaborative discussions (although an individual teacher can certainly examine student work or reflect on student thinking in isolation, there is a power in examining student work as a team).
- Structured protocols enhance the learning experience for participating teachers[13]. Although there are numerous protocols and guidelines, they all reflect a similar structured format for engaging in the study of student work. This protocol includes the following:

[13] Examples can be found at http://www.lasw.org

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- Identifying a focus or goal by answering the questions: What do we want to learn from the student work? What outcomes de we expect from the process? What data do we have to support our goal? How is our goal related to student performance and school wide goals and standards?
- Selecting student work that relates directly to the identified goal and outcomes. It is important that documentation be brought to the session that provides information on the objectives of the task the student responded to, the learning strategy or assessment strategies associated with the student work, and any other information that helps all participants better understand the context within which the student completed the work.
- Facilitated discussion of the participants' interpretations and understanding of the student work samples. All the projects emphasises that it is critical to ensure in-depth analysis of student learning ad teacher practice.
- Reflecting on the implications and applications of what is learned to reaching (highlight the way in which teachers can enhance their teaching based on what they have learned about student understanding of important concepts).

Implementation requirements:

- Focused time for discussion and reflection.
- The guidance of an experienced content expert (a facilitator with expertise in assessment might be helpful as well).

***Lesson study***

Brief description:

- Lesson study is a structured process through which teachers' develop lessons to enhance student learning in all subject areas.
- Use of lesson study results in teachers developing a thorough understanding of how a particular lesson should be conducted and why.
- Research lessons are at the core of lesson study –groups of teachers discussing, teaching, observing, and revising specific lessons that are designed to enhance student learning of specific concepts and content.

Key elements:

- Teachers collaborate in the development and refinement of lessons (in lesson study, teachers collaborate with each other in every aspect of the teaching process, from planning lessons to assessing students outcomes).
- The results of lesson study benefit all teachers and students (the concrete product of lesson study is well-researched, conceptually grounded lessons that promote students' learning of science or mathematics concepts).
- The focus of the lesson studied and researched is directly related to standards and school goals.
- Critical feedback is on the effectiveness of the lesson and not the teachers' performance while teaching (the focus of lesson study is on the lessons and the ways in which the teaching and learning strategies enhance student learning).

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- Enhancing teacher and student learning is grounded in practice.
- There is a structured process for guiding the lesson study[14]:
    - Defining the theme or concept to guide the lesson study: the theme, topic, or concept to be studied should be based on data indicating a need to improve student learning as determined by local, state, or national standards and goals.
    - Designing the lesson: teachers research the topic or concept of the study, including examining what the research says about how students learn the concept and what common misconceptions students hold, and then collaborate to develop a lesson plan, which I then shared with a larger group of teachers for additional feedback and revision.
    - Teaching de lesson: one teacher teaches the lesson, although all teachers participate in the preparation of the lesson and, sometimes, teachers role-play the lesson prior to teaching it in the classroom with students.
    - Observing the lesson: while the lesson is being taught, the other teachers observe and take notes on what the students and present teacher do and say, following the “storyline” of the lesson, and document the questions the presenting teacher asks and the student responses.
    - Reflecting and evaluating: critical, in-depth discussions focus on what was observed during the teaching of the lesson.
    - Revising the lesson: based on their reflections and evaluation, the lesson is collaboratively revised and, frequently, examining student work is used to guide decisions regarding how to enhance the lesson to increase student understanding and learning.
    - Teaching the revised lesson: the revised lesson is taught and observed; the same teacher may teach the lesson again, to either the same or a different group of students, or another teacher may conduct the lesson, and, often, additional faculty members are invited to observe when the revise lesson is taught.
    - Reflecting and evaluating: this second debriefing is attended not only by the lesson study teachers but also by a larger group of the faculty, the principal, and a “knowledgeable other” –a content expert, university faculty, or other outside professional.
    - Sharing the results: the lesson that has been researched and developed is shared with a broader audience of teachers and other educators.

Implementation requirements:

- Administrator support (for this intense process to happen, it might be necessary to structure the school day in ways that provide opportunities for teachers to plan, design, teach and reflect together).
- Access to resources and knowledgeable others.

***Immersion in inquiry in science and problem solving in mathematics***

Brief description:

[14] Lesson study is much more involved than simply organizing and conducting demonstration lessons with observation. The eight-step process of lesson study distinguishes it from this, and it requires real collaboration among teachers and ideally with external resources –people and research- to expand views.

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- Immersion in inquiry in science or problem solving in mathematics is the structured opportunity to experience, first hand, science or mathematics content and processes.
- By becoming a learner of the content, teachers broaden their own understanding and knowledge of the content that they are addressing with their students.
- By learning through inquiry and problem solving –putting the principles of science or mathematics teaching and learning into practice and experiencing the processes for themselves- teachers are better prepared to implement the practices in their classrooms.
- The goal is to help teachers to become competent in their content and reflective about how to best teach it.
- Immersion experiences are usually guided by knowledgeable and experienced facilitators with expertise in science or mathematics.
- The curriculum is designed specifically to highlight the processes of inquiry and mathematical problem-solving approaches to learning mathematics and science content.

Key elements:

- Immersion in an intensive learning experience.
- One goal is learning how students learn science and mathematics (engage teacher in first-hand learning of what they are expected to practice in their classrooms – guiding students through inquiry-based science or mathematical problem solving).
- Teachers' conceptions about science, mathematics, and teaching change. One outcome is the change of teachers' conceptions about the nature of science or mathematics learning and teaching.

Implementation requirements:

- Qualified facilitators
- Long-term experiences (immersion in science inquiry and mathematical problem solving require in-depth, over-time learning that cannot be accomplished in one-shot workshop).

***Immersion in the work of scientists and mathematicians***

Brief description:

- The vast majority of science and mathematics teachers have never had the opportunity to actually "do" science or mathematics in a real-world setting. The situation perpetuates certain myths about the nature of science and mathematics because most teachers do not have practical experience in the files they are teaching.
- Immersion in the world of scientist and mathematicians is one way to resolve this and provides an opportunity for teachers to strengthen their knowledge base in content areas by becoming active participants in a mathematics or scientific community.

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- The purpose of this approach is for teachers to learn science and mathematics content; to learn elements of the research process, such as designing experiments, creating mathematical models, and collecting, analysing, and synthesising data; and to develop a broader and increased understanding of the scientific and mathematics approaches to building knowledge and solving problems.

Key elements:

- The experienced are designed as mentored research opportunities for teachers, as apprentice researchers, to learn the content, process, culture, and ethos of scientific or mathematics research and development work.
- Teachers attend lectures and seminars and read materials on the science or mathematics topics related to the research.
- Teachers actively participate as members of research teams, which include scientists or mathematicians or university faculties.
- The program includes planning for how to connect learning to teachers' classrooms.
- Teachers document their learning and reflect on their experiences (many immersion programs incorporate keeping a journal or writing about the immersion experience).

Implementation requirements:

- Funding
- Access
- Shared expectations and goals.
- Resources and support (to return to the classroom and use what they have learned).

***Coaching***

Brief description:

- Coaching is a PD strategy that provides one-on-one learning opportunities for teachers focused on improving science and mathematics teaching by reflecting on one's own and/or another's practice.
- It takes the advantage of the knowledge and skills of experienced teachers, giving them and those with less experience opportunities to learn from each other.
- Over the years, particular forms of coaching have emerged (incorporating all a traditional supervisory model focused on classroom observations and the use of a pre-conference – observation – post-conference cycle).
- More recently, coaching as a form of professional learning has shifted to focus less on the supervisory model and more toward collaborative, peer learning.
- In this model, the goal of coaching is to enhance the learning of both the coach and the teacher being coached and the role is characterised by facilitation of learning and not on evaluation practice.
- Styles of coaching:

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- *Direct information style of coaching*: when the coach directs the conversation by providing pertinent information (for instance, for teachers that are just learning a new curriculum model and have a high need for structure).
- *Non direct style of coaching*: coaches listen, clarify, and encourage the other teacher to present their ideas (when the teacher has a low need for structure and is simply needing to "talk through" which of several strategies he or she might use in the classroom).
- *Collaborative style of coaching*: the coach and the teacher engage in a collegial exchange of ideas and co-plan/problem solve (when teachers have a moderate need for structure, that is, they have some ideas and some challenges to work through).

- The purpose of most coaching is to enhance the use of specific curriculum, instructional materials, or teaching strategies.

Key elements:

- Teachers focus on learning or improvement (coaching is most successful when teachers agree that they will work on examining particular teaching techniques, student interactions, perplexing problems, or learning strategies. When coaches observe in classrooms they need a predetermined focus that they agree on with the teacher being observed).
- Mechanisms for practice and feedback are critical (for classroom observations, pre-conferences typically are opportunities for the coach and the teacher to agree on the focus and set ground rules about the kind of feedback that will be helpful. Post-conferences, then, are guided by these agreements).
- Coaching requires that teachers have opportunities for interaction.

Implementation requirements:

- A climate of trust, collegiality, and continuous growth (coaching relationships are strengthened by a willingness to take risks and learn from failures).
- Long-term commitment to interaction (teachers in coaching relationships also must build an understanding about what each knows about teaching, learning, and content).
- Skill building in coaching (coaching requires special skills in communication, observation, and giving feedback).
- Administrative support

***Demonstrating lessons***

Brief description:

- Demonstration lessons are professional learning opportunities that are practice based and provide an opportunity for enhancing teacher practice and reflection.
- The term refers to a master, experienced teacher or facilitator presenting an exemplary model of teaching that other teachers observe and then discuss.
- Observing teachers are expected to gain insights and ideas for use in their own classrooms and often to implement what they observe.

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- Unlike *lesson study* that is focused on fine-tuning a lesson, demonstration lessons aim to help teachers actually see what it looks like to teach in particular ways. They may focus on how the teacher identifies and addresses students' prior conceptions or on the questions a teacher asks of students as they explain how they solved a mathematics problem.
- The purpose of demonstration lesson is not always to teach an exemplary, model lesson to other teachers but rather to use a "pre-lesson – classroom demonstration – lesson observation – post-lesson debrief" cycle as a catalyst for in-depth reflection on science and mathematics teaching and learning.
- In the same way teachers use students work as a means for increasing their understanding of student understanding, teacher work –in this case, classroom teaching – is used as a means for increasing understanding of teaching practices specific to mathematics and science education.
- Demonstration lessons are often used as a strategy in combination with other professional learning strategies, such as with curriculum implementation, action research, study groups, lesson study, or case discussions.

Key elements:

- Groups of teachers observe each other (in contrast to *coaching* or *mentoring* in which one-on-one observation occurs. Interactions of groups of teachers lead to more diverse discussions, bring varied perspectives to the discussions, and provide an opportunity to observe different teaching approaches. Together, they develop a shared vision of what teaching and learning should look like).
- There is a cycle of pre-discussion, observation, and post-discussion:
    - Pre-discussion: teachers learn about the goal and purposes of the specific lesson they will observe, become familiar with the instructional materials used in the lesson, and hear from the teacher whose classroom the lesson will be taught in about what students have done prior to this lesson to build conceptual understanding of the content.
    - The lesson is then taught by a teacher leader in one of the teacher's classrooms, co-taught by the teacher leader and teacher, or taught by the teacher himself or herself with his or her own students. The observing teachers take notes and attend to specific classroom practices identified during the pre-discussion.
    - Post-discussion: engages teachers in a dialogue regarding what was observed – usually after the demonstration teacher reflects on what he or she experienced and perceived – and the facilitator raises issues related to content, pedagogy, instruction, or assessment that were related to the teaching of the lesson.
- Observations and discussions are facilitated (although it could be conducted without a "trained expert", teachers as a group need a clear focus and purpose for their discussions and observations, and the facilitator enhances the dialogue among the teachers, raising important issues).
- A clear purpose and intent focus the discussions and observations.

Implementation requirements:

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- Time and structure (it is job embedded, it occurs during the school day, teachers need protected time to interact with each other).
- Critical reflection in a risk-free environment (it is essential that teachers feel comfortable with each other and have experience critiquing teaching practices in a nonthreatening environment before engaging in observation).
- A process of examining lessons (it requires that teachers agree on and use a common structure and process for documenting their observations. This can include note taking, scripting of observations, or videotaping or lessons).

***Mentoring***

Brief description:

- Mentoring, like coaching, is a teacher-to-teacher PD strategy that sustains long-term, ongoing professional learning embedded within the school culture.
- Mentoring usually occurs between a teacher new to the filed and a more experienced teacher or an experienced teacher taking on a new role or new teaching approach[15] (effective mentors also serve as a coach to the new teacher).
- A mentor is an experienced teacher who serves as content specialist, guide, provider of resources, advocate, facilitator, coach, and collaborator with the goal of enhancing science and mathematics teaching practices of a less experienced teacher (typically teachers with more content knowledge or experience using a particular curricular program or teaching practices, sometimes scientist and mathematicians helping teachers to develop an increased understanding of the content they are teaching and to incorporate discussions on real-world applications in their teaching of science and mathematics content).
- They also take the role of “problem solvers for instructional dilemmas” to help teachers address many of the challenges in their first years of teaching.

Key elements:

- The mentoring relationship focuses on science and mathematics content and pedagogical content knowledge.
- New teachers and mentors have valuable expertise to share with each other.
- It is essential to have mutual agreement and understanding on the goal and purpose of the mentoring relationship.

Implementation requirements:

- Mentor competencies: mentors need their own PD and orientation to their roles. Although a mentor may have extensive experience as a teacher of students, mentoring adults requires additional knowledge, skills, and abilities including the following:

[15] In contrast with coaching, which can and often does involve two experienced teachers, although one of the teachers might have more expertise in a certain area, such as with a specific teaching approach or with a set of instructional materials

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- Establish a climate of peer support.
- Model reflective teaching practices.
- Stay current on research.
- Structure for assignments.
- Time.

***Workshops, institutes, courses, and seminars***

Brief description:

- Workshops, courses, institutes, and seminars are structured opportunities for educators to learn from facilitators or leaders with specialized expertise as well as from peers:
  - *Institutes and courses provide opportunities for participants to focus intensely on topics of interest for weeks or for an extended period of time.*
  - Workshops and seminars tend to be offered for shorter periods of time and address more discrete learning goals.
  - Workshops typically include more experiential or hands-on activities through which participants engage with new ideas and materials.
  - Seminars tend to be more oriented to sharing knowledge and experiences through discussions and reactions to others' practice or research results.
- Features of effective learning sessions like workshops, institutes, courses, and seminars[16]:
  - Clear purpose and outcomes: Participants know the goals, expectations, purposes, and benefits of the session(s).
  - Value: The session offers value to the participants by addressing their goals for learning and growth.
  - Variety: A variety of learning activities are combined that engage participants and appeal to different learning styles.
  - Networking: Session(s) provide time for participants to interact with each other and build relationships with new colleagues.
  - Effective use of time: effective sessions make "every minute count." For example, lunch discussions can be tailored to help participants process the content of the morning and to network.
  - Quality of leaders and facilitators: The facilitators know their content well and are skilled in effective adult learning methods. They understand and respond to the goals of the participants.
  - Ongoing evaluation: Sessions are evaluated daily and feedback is used to make adjustments and enhance future sessions.
  - Quality of content and design: The content is "credible, sound, current, and interesting".
  - Resources: Participants get access to print or electronic resources that extend their learning and provide them with reference material to use in the future.
  - Products: Participants are guided to develop artefacts or products that reflect what they are learning. These include plans, conceptual frameworks, assessments, or maps of their progress or thinking.

[16] According to Mundry, Britton, Raizen, & Loucks-Horsley (2000).

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- Right audience: The session communicates clearly about its goals and purposes to target the right people for participation.

Key elements:

- Clearly stated goals are communicated to the participants.
- A leader or facilitator guides the participants' learning.
- Group structures necessitate a collegial learning environment (because these strategies are intended for groups of people, the learning environment should be designed so that it is collegial for participants to learn from one another and from the leader of the session).
- Workshops, courses, seminars, and institutes can use, among others:
    - The "training model" (explanation of theory, demonstration or modelling or a skill, practice of the skill under simulated conditions, feedback about performance, coaching in the workplace).
    - The "NCISE model" (invite, explore, explain, and apply).
    - The "5 Es Model" (engagement, exploration, explanation, elaboration, and evaluation).

Implementation requirements:

- Expert knowledge
- Time away from the workplace, with arrangements for substitutes or stipends.
- Curriculum or syllabus (learners should know what content they will learn through the professional development experience).
- Access to resources and materials.
- Incentives.

The choice of PD strategies depends both on the intended outcomes and on the purpose each strategy best addresses.

In relation with the outcomes, Loucks-Horsley et al. (2003) differentiate between:

- Increasing science and/or mathematics content knowledge.
- Building pedagogical content knowledge
- Building a professional learning community.
- Developing leadership.

*Increasing teachers' content knowledge is often best accomplished by immersing teachers in content as learners themselves. This can be accomplished through the immersion strategies, through partnerships, and in workshops/institutes. But learning content alone will not lead to changes in teaching, so designers must build in opportunities for teachers to put the content they learn into the context of teaching and provide opportunities to develop pedagogical content knowledge. This is accomplished through different strategies, such as examining student work, case discussions, curriculum work, and lesson study. Engaging in such*

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*collegial arrangements help to address the third outcome (building a professional learning community), which can also be developed through teachers' participation in lesson study, demonstration lessons, and study groups. The final outcome is often addressed through the use of the developing professional developers strategy.* (Ibid. p. 114)

In relation with the purposes better addressed by each strategy, they consider that:

- *Strategies that focus on developing awareness* are usually used during the beginning phases of change, which call for introducing teachers to new approaches or content. Examples are: professional networks, demonstration lessons, and study groups.
- *Strategies that focus on building knowledge* provide opportunities for teachers to develop science and mathematics CK and PCK. Examples are: case discussions, immersion experiences, workshops, and partnership with scientist or mathematicians.
- *Strategies that help teachers to translate new knowledge into practice* engage teachers in drawing on their knowledge base to plan instruction and improve their teaching. Examples are: coaching, mentoring, and demonstration lessons.
- *Strategies that focus on practicing teaching* help teachers learn through the process of using a new approach, practice, or process with their students. As they practice new moves in their classrooms, they increase their understanding and their skills. Examples are: examining students' work, lesson study, coaching, mentoring, and demonstration lessons.
- *Strategies that provide opportunities to reflect deeply on teaching and learning* engage teachers in examining their experiences in the classroom, assessing the impact of the changes they have made on their students, and thinking about ways to improve. These strategies also encourage teachers to reflect on others' practice, relating it to their own and generating ideas for improvement. Examples are: action research, study groups, lesson study, case discussions, and examining student work.

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Designing your PIRMAS CPD programme

In this section, the main features of PRIMAS professional development programme will be introduced as well as suggestions on how to organize it.

## The aim

To offer a clear and deep vision of the professional development materials offered by PRIMAS as well as a possible ways to deliver PRIMAS.

## The outcome

You will use PRIMAS materials and the professional development strategies to design the professional development programme you will be responsible of, considering the aims and your local context.

## Contents

- Aims of PRIMAS continuing professional development programme
- Context and other critical issues
- PRIMAS continuing professional development modules and platform
- Guidelines about how to organize PRIMAS CPD programme
- Case study: PRIMAS in different countries

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## Aims of PRIMAS continuing professional development programme

The overall aim of PRIMAS project is to promote a more widespread uptake of inquiry-based learning in mathematics and science at both primary and secondary levels across Europe, in line with the recommendations of the Rocard report (2007).

The continuing professional development programme you will design and implement, with the support of your PRIMAS national team, will address one of the key groups that can make this happen: teachers, both in-service and pre-service.

The project PRIMAS will carry out other supporting actions that will create the climate of change we want to spread. However , it is important to stress, from the very beginning, that neither PRIMAS nor your intervention with teachers aims to replace the existing curriculum and/or pedagogical practices. We are aiming to enrich mathematical and scientific experiences students live at school through a widening of teachers' knowledge, pedagogical practices, beliefs and attitudes.

For any CPD programme, one of the main decisions is to set up a collection of aims the programme will reach. This collection of aims should be brief, concrete, and attainable. Moreover, these aims should be shared with participants at the very beginning, the progress towards them should be continuously monitored, and, if necessary, these aims might be adapted.

According to Loucks-Horsley et al. (2003), when designing professional development, there are different kinds of goals:

- Goals for student learning
- Goals for teacher learning
- Goals for teacher practice
- Goals for organization

In order to set up a collection of aims with these characteristics, the analysis of your local/national context as well as the critical issues that will affect your work is necessary (see next sub-section). However, we will propose a set of aims that might help you to devise your specific aims:

- *Aims for student learning*
    - To develop students' mathematical and scientific competencies.
    - To engage students' in meaningful, motivational and enjoyable learning experiences in mathematics and science.
    - To create a students' view of mathematics and science as a field of inquiry and not just as an ossified collection of facts and procedures.

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  - To develop students' confidence in their own capacities to deal with complex and unstructured problems.
  - To develop students' inquiry competency as a part of the development of their lifelong learning competency.

- *Aims for teachers learning*
  - To deepen teachers' mathematical and/or scientific knowledge.
  - To increase teachers' knowledge related to inquiry in mathematics and science.
  - To widen teachers' pedagogical knowledge with knowledge about IBL pedagogies.
  - To promote teachers' view of mathematics and science as a field of inquiry.

- *Aims for teacher practice*
  - To help teachers to develop a set of professional skills to support the use of IBL situations in their classroom.
  - To encourage teachers to implement IBL pedagogies and to reflect about them.
  - To support teachers in their process of change and professional growth towards IBL.

- *Aims for the organization*
  - To set a structure to effectively support teachers.
  - To promote collaboration between teachers, teachers networks and teachers' professional culture.
  - To establish and deepen sound contacts with institutions and/or centres which are in charge of providing PD in order to support PRIMAS CPD.
  - To promote, support and expand the professional development culture of teachers.

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## Context and other critical issues

One of the main challenges of PRIMAS is that it is a cross-European project. PRIMAS CPD programme will be adapted to 12 different countries, each one with its own particularities and context.

From the analysis of needs we already have carried out, we know that in most of the countries, both the curriculum and the policy level support a wider implementation of IBL in the daily teaching practices.

However, we know as well that there are some important obstacles to overcome. For instance, the content knowledge of primary school teachers and the pedagogical and pedagogical content knowledge of secondary school teachers. Also the possible resistance of parents to a change that they are not used to. Besides, other structural factors (like the distribution of school time, the availability of materials to carry out experiments, the pressure from the school system to cover the syllabus, or external assessment, among may other factors) might act also as barriers for the implementation of IBL.

A specific analysis of the context and other critical issues that may support/affect the implementation of PRIMAS should be carried out in each country/region. For the countries participating in PRIMAS, the "analysis of needs report" summarizes valuable information about the situation. For countries outside PRIMAS, it is something that they should carry out before they plan how to organize and implement PRIMAS CPD.

Based on Loucks-Horsely et al. (2003), some of the contextual factors you might reflect on when planning PRIMAS CPD will be:

- National/regional/local educational policies.
- National/regional curriculum, standards and students' learning outcomes.
- Teachers and teachers' learning needs.
- Teachers' current pedagogical practices, assessment and the learning environment.
- Organizational culture within school and between schools.
- Available resources
- Teachers' history and culture about professional development.
- Parents and the community.

Obviously, in our case all this reflections will be mediated by the objective of promoting IBL.

The analysis of these contextual factors will help you to select the most appropriate professional development strategies and materials, and better support teacher in their professional growth.

Moreover, other critical issues you might consider to analyse are:


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- Time: finding time is a critical issue. In order to attend to workshops, courses or seminar, to be engaged in group work, or preparing the implementation of new lessons, teachers need time, which often is difficult to find. The effective use of the time is then a main issue.
- Building a professional culture: if we want teachers to be engaged in collaborative professional development initiatives, a specific professional culture is needed. A culture focused on continuous learning, which promotes shared responsibility for learning, which includes collaborative and collegial interactions as a way to “deprivatize” teaching, and which routinely supports and engage teachers in collaborative inquiry and dialogue (Loucks-Horsley, 2003, p. 91). Sometimes this culture is already built and we just have to support it, other times it is necessary to start developing it.

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## PRIMAS continuing professional development modules and platform

In order to support teachers' learning, PRIMAS has developed a set of modules that deal with specific aspects of teaching through IBL in mathematics and science.

These modules explore some of the pedagogical challenges that arise when introducing investigative, non-routine problem solving activities to the classroom.

The modules are activity-based; built around a collection of example classroom activities. The intention is that, as part of the Professional Development (PD) process, teachers will plan inquiry-based lessons to use with their own class and, at a later meeting, report back on their experiences.

Each module includes a PD session guide and handouts for teachers, as well as sample classroom materials and suggested lesson plans. Several of the lessons include the use of simple computer software.

Also included, there are several video sequences showing teachers trying these materials with their own classrooms. These form a stimulating basis for discussion during the PD sessions.

You will find these modules in the PRIMAS website (http://www.primas-project.eu ).

In the next table we will briefly summarise each module:

| *Module* | *Description* |
|---|---|
| Student-led inquiry | In this module, teachers will be encouraged to experience what it feels like to think like a mathematician or scientist, and reflect on the role shifts that are necessary for students to share this experience in the classroom. Teachers are shown phenomena and situations and are invited to pose and pursue their own questions. This experience is then transferred to the classroom. |
| Tackling unstructured problems | This unit compares structured and unstructured versions of problems and considers the demands and challenges unstructured problems present to students and teachers. |
| Learning concepts through inquiry | This unit considers how the processes of inquiry based learning may be integrated into the teaching of Mathematics and Science content. |
| Asking questions that promote IBL | This unit contains a selection of professional activities that are designed to help teachers to reflect on:<br>• characteristics of their questioning that encourage students to |

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| | |
|---|---|
| | reflect, think and reason;<br>• ways in which teachers might encourage students to provide extended, thoughtful answers, without being afraid of making mistakes;<br>• the value of showing students what reasoning means by 'thinking aloud'. |
| Students working collaboratively | This unit is designed to offer the professional development provider some resources that will help teachers to:<br>• consider the characteristics of student-student discussion that benefit learning;<br>• recognise and face their own worries about introducing collaborative discussion;<br>• explore techniques for promoting effective student-student discussion;<br>• consider their own role in managing student-student discussion;<br>• plan discussion based lessons. |

Moreover, PRIMAS websites offers a variety of professional development resources and IBL-oriented classroom materials (Fig. 6). A filtering tool (Fig. 7), both in the top and in the bottom of the page, will help you to find the kind of resource you are looking for.



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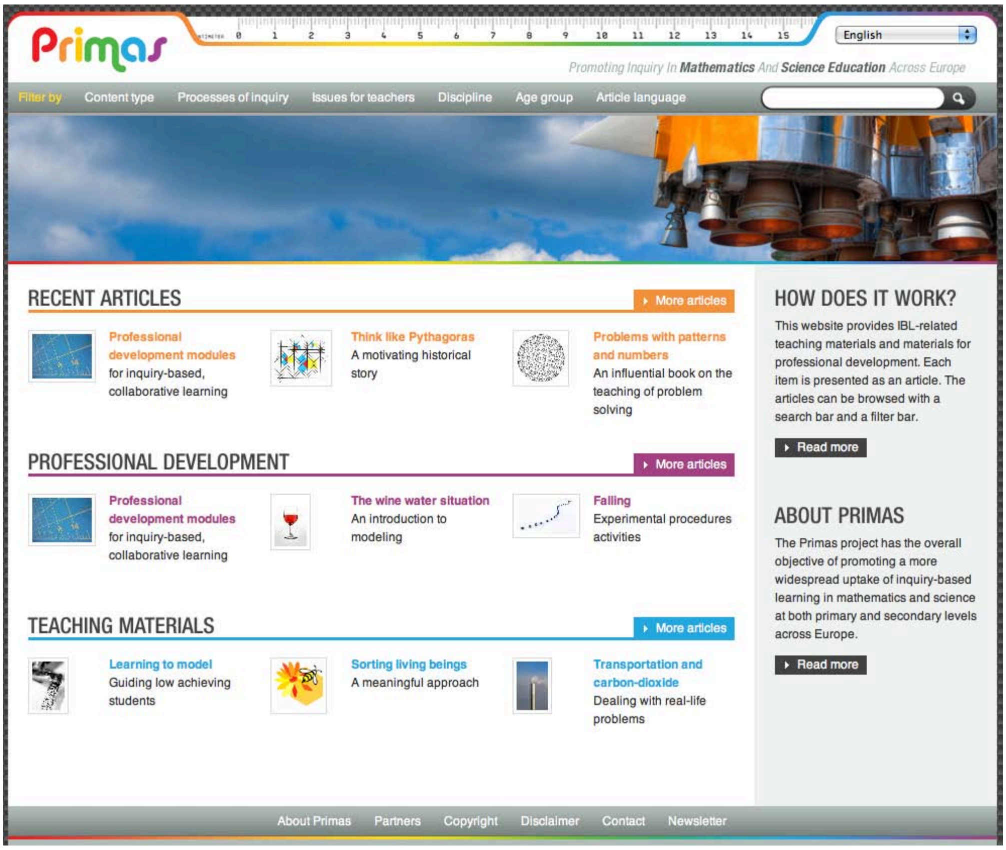


Fig. 6. PRIMAS platform offering PD and classroom materials

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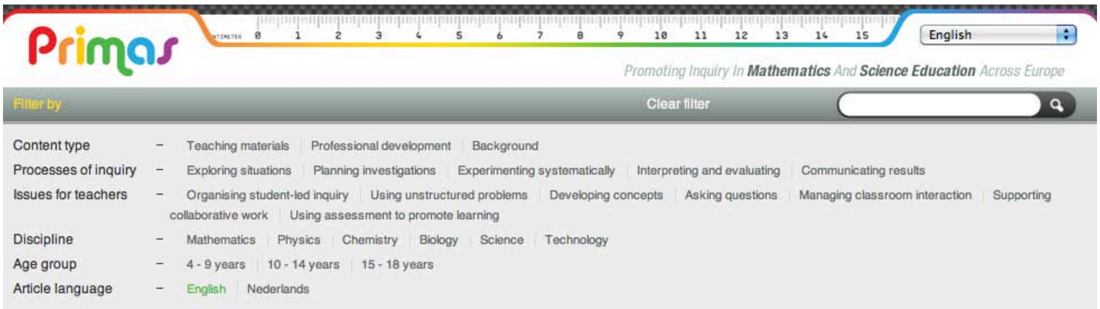


Fig. 7. Filtering tool in PRIMAS site.

## Guidelines about how to organize PRIMAS CPD programme

Through this guide, you have learn about IBL, about teachers' professional learning and about professional development models and strategies. Moreover, you have refined PRIMAS CPD aims, you have reflected about your context and other critical issues. Finally, you have had access to some PD modules.

Everything is like the pieces a puzzle, which can be arranged in many different ways. It is the time for you to create you own puzzle.

What we know from the literature on PD is that teachers need time and support to change their practices. We know as well that a balanced collection of PD strategies should be used during this time in order to effectively support teachers. Moreover, we know that PD is more effective when teacher participate actively, when they collaborate with their colleagues, when they have the opportunity to practice new approaches and to reflect about this practice. Finally, we know that students' learning outcomes is a main driving force for teachers to engage on PD and stay within the programme.

Visually, we can think about teachers' growth using a spiral model. The fact that the spiral is infinite encapsulates the idea that teachers are continuously growing. The fact the spiral progress in circle, somehow revisiting old "places" but in a higher level, encapsulate the idea that several cycles of implementation and reflection are needed. This process of growing could be described, in a very simplistic way, as cycles of "analysis – implementation – reflection".

In them more traditional way of teachers' professional development, the "analysis" phase is normally associated with training courses and workshops. But there are other multiple alternatives, some of them including explicitly the "implementation" phase (e.g., *lesson study* or *action research*); others offering different ways of organizing the "analysis" phase (e.g., *study groups* or *coaching*).


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Within the PRIMAS project, a 2 years PD programme will be implemented. According to some research, this is considered as the minimum intervention to get some impact on teachers' beliefs and practices. In this 2 years, it will be your responsibility, together with the support of your PRIMAS national team, to organize the PD activities in which you will want to get your teachers involved.

To do that, you will have the support of the PRIMAS platform, where you will find the PD modules and other materials (other PD materials and classroom materials). They way you use them to weave your particular PD programme depends on many factors we cannot anticipate. Any way, apart from the contextual factors, two main issues will be:

A. The starting point of the teachers you are working with, in relation to IBL.
B. The reaction and feedback you will get from them during their PD progress.

Point A. is absolutely crucial when you are launching the CPD programme. Point B. will be important for you to be adaptable to the teachers needs.

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## Case study: PRIMAS in different countries

[To be completed for the final version, once PRIMAS is implemented in different countries]

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