Final versions of the initial package of classroom materials and guidelines

mathematics and science for life

mascil

mascil aims to promote a widespread implementation of inquiry-based teaching (IBL) in math and science in primary and secondary schools. It connects IBL in schools with the world of work making math and science more meaningful for young European students and motivating their interest in careers in science and technology.

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Executive Summary

The main aim of the *mascil* Work Package 3 'classroom materials' is to present guidelines and an online collection of teaching materials that encourage and support teachers to design their own classroom materials that connect IBL and the WoW in mathematics and science education.

The collection presents 'good practices' of IBL classroom materials that connect to the World of Work (WoW) and is supported by established guidelines.

This deliverable shows our research into collecting and analyzing IBL classroom materials that connect to the WoW and explains how we use this analysis to judge the usefulness of existing classroom materials for the *mascil* project.

The final collection of classroom materials will be presented in an online database at the end of 2016, the current collection (about 20 'core examples' within a total of 40+ tasks) is already available at the European *mascil* website.

The project *mascil* consists of 18 teams in 13 countries and aims to promote a widespread use of inquiry-based science teaching (IBST) in primary and secondary schools. The major innovation of *mascil* is to connect IBST in school with the world of work making science more meaningful for young European students and motivating their interest in careers in S & T. As a first step we will identify and review existing classroom materials that develop mathematical, scientific and interdisciplinary inquiry in rich vocational contexts (for primary and secondary school pupils). Through these materials students will experience and understand the usefulness of skills and knowledge learned at school, because they experience purpose and utility, leading to a greater interest as well as motivation for mathematics and science.

The first official release of the classroom material collection (deliverable) is presented in a detailed report below. The report is organized around the core tasks that have accomplished by the leading team in cooperation with the whole mascil Consortium and led to the current online presentation of the materials collection.

In the Annexes a detailed description of the classroom task structure and the final version of the (re)design Guidelines can be found.

1. Introduction

The heart of the mascil project is to promote more meaningful and motivating science and mathematics teaching and learning. Our approach more closely connects school to the world of work in IBL lessons. Inquiry-based learning aims to develop and foster inquiring minds and attitudes that are vital for students to be able to successfully take on their future roles as productive and capable citizens in our modern, global society.

Fundamentally, IBL is based on students adopting an active, questioning approach. The tasks they address are supposed to be experienced as real and meaningful as they explore problem situations and evaluate results. Learning is driven by open questions and multiple-solution strategies. IBL is a perspective on learning that creates a new learning culture in the classroom.

The main objectives of WP3 are as follows:

- Identify examples of classroom materials for inquiry in rich vocational contexts;
- Develop guidelines for teachers for developing IBST-oriented classroom materials for science and mathematics using workplace contexts from industry
- Produce exemplary materials, in close collaboration with mathematics and science teachers, vocational education teachers and stakeholders from industry, which allows students to get insights into the usefulness of mathematics and science in the world of work

The research design during Month 1 to Month 18 has a breakdown in four tasks.

Task 1 (page 6)	*Analysis of existing examples of classroom practices and workplace contexts.* The first task is to identify and analyse already existing IBST classroom materials that connect mathematics and/or science with meaningful contexts from vocational studies areas and/or industry. We have looked for the best examples of suitable classroom activities from Europe and beyond. By month 6, the first collection of materials was available. All partners contributed examples from their own work and from their collaborations with research centers and universities from around the world.
Task 2 (page 8)	*Develop guidelines for developing IBST- oriented classroom materials.* WP3 (supported by the other WPs) wrote a first version of guidelines for teachers (from general and vocational education) on how to develop IBST-oriented classroom materials in rich vocational contexts. These guidelines offered a common framework and methodology to develop inquiry-based classroom materials connected with vocationally situated rich contexts and developing key mathematical and scientific competencies.
Task 3 (page 14)	*Piloting and reviewing materials.* The materials & guidelines were piloted in partner countries with selected teachers, who gave feedback.
Task 4 (page 17)	*Initial material package for teachers (guidelines + classroom materials).* Based on task 1 to task 3 the guidelines and classroom materials were finalized and sent to all partners for translation.

Each task will described in terms of the research method used and the results.

2. The Four Tasks of this Deliverable

Task 1 - Analysis of existing examples of classroom practices and workplace contexts

In the first six months every country participating in *mascil* was invited to share examples of 'good practice' classroom materials that connect Inquiry Based Learning (IBL) and the World of Work (WoW). Let's have a closer look at the definition of IBL. This kind of learning is defined to be inductive, student-centered and focused on collaboration (Doorman, 2011). IBL aims to develop and foster inquiring minds and attitudes that are vital for students being able to face and manage uncertain futures. Fundamentally, IBL is based on students adopting an active, questioning approach. The problems they address are experienced as real, they inquire and pose questions, explore problem situations and evaluate results. Learning is driven by open questions and multiple-solution strategies.

Teachers are proactive: they support and encourage pupils who are struggling and extend those that are succeeding through the use of carefully chosen strategic questions. They value students' contributions – including mistakes – and scaffold learning using students' reasoning and experiences (Crawford, 2000).

The other dimension that is leading within the *mascil* project is the 'World of Work'. *mascil* bridges the gap between the classroom activities and the WoW by using rich vocational contexts.

To make a good analysis of possible classroom materials, a first set of classroom tasks was selected (in December 2012/January 2013) by the staff of WP3.

In order to involve every member in this project the Delphi method was applied to achieve consensus about key concepts in *mascil*. Delphi method is a commonly used and reliable research method for achieving consensus over opinions (Hsu & Sandford, 2007) and a suitable method when dealing with incomplete information about the stated problem (Skulmoski, Hartman & Krahn, 2007).

During the kick-off meeting, in Freiburg, ten examples of the collected classroom materials were presented and used to enhance further discussion. Following on the Freiburg meeting a questionnaire was sent to all collaborating members in the *mascil* project in which they were asked to send more examples and provide reasons for their choices of materials. Again these questionnaires were gathered and documented for further analysis. Meanwhile a theoretical discussion about the World of Work and its definition arose by email. This discussion involved work packages 3, 4, 5, but also 8, 9 and 1.

Work Package 3, 4 and 5 had another meeting (spring 2013) to discuss the contributed classroom materials, their further use in the other work packages of *mascil* and to construct a framework to characterize the relation to the WoW, again discussion were

recorded. All these conversations and opinions were used to re-analyze and better characterize the classroom materials that connect IBL to the WoW. Meanwhile early findings of this analysis were presented by email to the other members of *mascil* enhancing further discussion.

To finalize the first task for characterizing the materials a meeting in Utrecht was held (in June 2013) involving the Dutch project members.

Results

Analysis resulted in additions - regarding the WoW- to the IBL framework designed in the PRIMAS-project (Doorman et. al. 2011), see task 2 for the next steps. The first version of the online collection was settled (Figure 1).
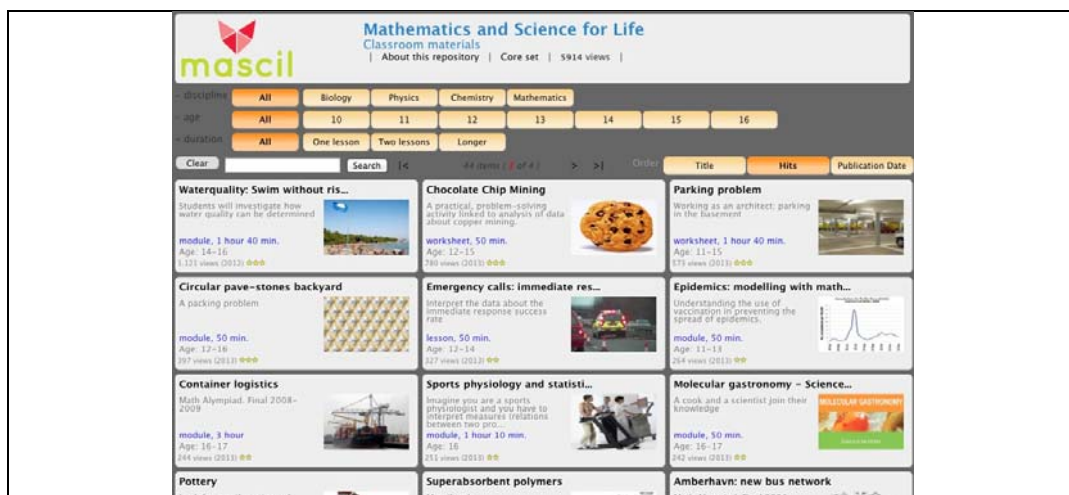
Figure 1: Online collection of *mascil* materials (visited: May 2014)[1]

Further work

An extra selection option was defined (duration of the task), this was implemented in the database in month 11. During task 2 , 3 and 4 the characteristics of the exemplary materials form the basis for the design of a set of guidelines for collection, selecting and designing further *mascil* activities by teachers and transversal working groups.

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[1] http://www.mascil-project.eu -> classroom materials

Task 2 - Developing guidelines for developing IBST-oriented materials

First we briefly give our theoretical background for this task 2. This *mascil* project aims to have students experience purpose and utility of mathematics and science and, consequently, be more motivated for carreers connected to these subjects. Purpose and utility are defined by Ainley, Pratt, & Hansen (2006): (1) Purpose is seen to be the meaningful outcome it creates for the student and (2) Utility does not only show the ability to carry out a task, but also the construction of meaning in a way that is useful for the student. Meaningfulness is derived from its outcome, using knowledge in doing; relevance is inseparable from knowledge and knowing how to do something (Chevallard, 1988). The didactics of IBL assume that learning is a constructivist process. (Social) constructivist learning theories state that the learner actively creates his own knowledge and that social relations are important for the creation of knowledge (Bruning, Schraw & Ronning, 1999). Emphasis is laid on cognitive activity; explaining and creation of own knowledge (Mayer, 1999). Together with our first findings from Task 1 we defined the *mascil* Framework: six categories are described in the framework (Figure 2) .
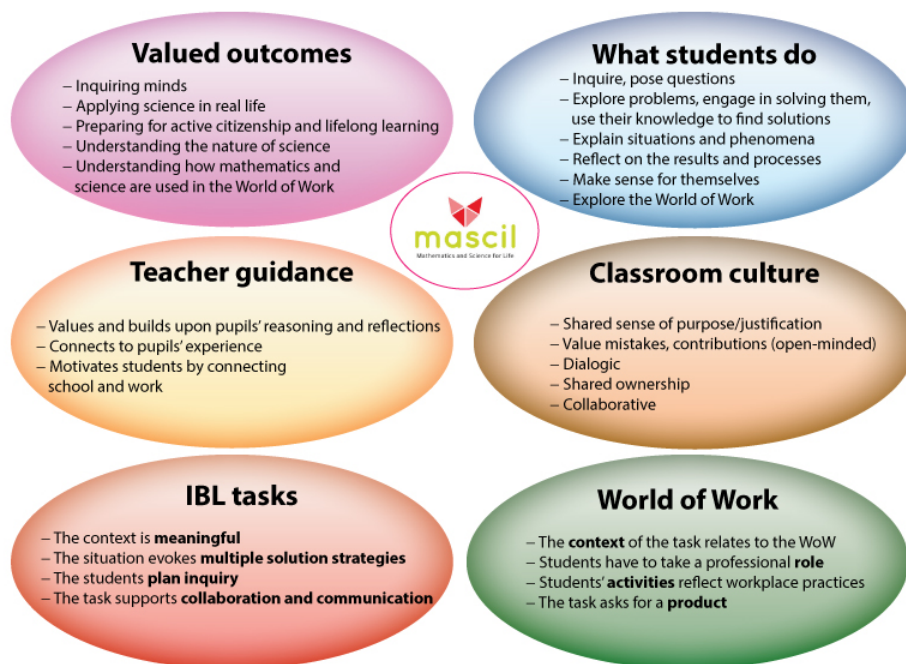

Figure 2: The *mascil* Framework: Six dimensions clarifying IBL & the World of Work (source: mascil[2])

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[2] http://www.fisme.science.uu.nl/en/mascil/

In the cloud 'World of Work' four dimensions are given: Context, Role, Activity and Product.

The **context** in which the task is set relates to the WoW. This relation can be very strong if an (authentic) practice from the WoW is used as the rich context for learning. It should provide a clear purpose and a need to know.

The relation between the context and the WoW may also be weak, if for example the task is set in the context of the WoW, but this context is just a 'superficial wrapping' of the task, and does not remain important when working on the task.

The **activities** students do in the task are related to authentic practices from the WoW. The activities can be more or less similar to activities actually done by workers in the workplace . Also the ways of working reflect characteristics of daily work, like for example teamwork, division of labour/tasks etc. The activities should have a clear purpose, involve authentic problems and reveal how mathematics and science are used. The focus in the activities is on students using mathematics and science in ways and in contexts related to the WoW. If students' activities are very similar to typical problems in textbooks for mathematics and science, the connection between activities and WoW is weak.

Within the task students are placed in a **professional role** fitting the context of the task. The actions students perform can be more or less similar to authentic workplace actions and to the ways of working in a workplace. In some sense students step out of their role as a student.

The outcome of the task is a **product** made by the students in their role as professionals, meant for an appropriate audience. The product is similar to real products from the WoW.

For a task to be strongly connected to the WoW its relation to the WoW on the dimensions context, role, activities and products should be explicit, well aligned and clear to the students. Not every task will have a similar emphasis on each of these four dimensions, but for a strong connection with the WoW these dimensions need to be taken into account in the actual (re)design of tasks for students.

Example - Chocolate Chip Mining

This is one of the *mascil* tasks, taken from the online repository.

Abstract
Part 1 Mineral processing. This is a practical activity which should have a wide appeal. It uses the problem of mining chocolate chips in a biscuit as an analogy for the difficulties involved in developing mineral resources. Part 2 Copper mining. This is a data-analysis exercise which is designed to show the real-life importance of the analogy used in Part 1.

Duration
two lessons

Documents

- Youtube: Mine Engineering (for introduction)
- Worksheet pdf, Worksheet docx
- Teacher pdf, Teacher docx,
- Original SATIS source

>>> Detail

❓ Inquiry Learning

The mode of teacher use is key to securing the IBL aspects of the task. Teacher needs to raise questions about how to extract chocolate 'core' from its parent 'rock' in the purest form. Raise questions about yields and explanations for variation in yield etc.

Inquiry Learning Dimensions

- Exploring situations
- Planning Investigations
- Experimenting systematically ✓
- Interpreting and evaluating ✓
- Communicating results ✓

Discipline
- Mathematics
- Biology
- Physics
- Chemistry ✓
- Engineering ✓

Target group
- Primary Education
- Lower Secondary Education ✓
- Upper Secondary Education

Age range 14–16

Mascil partner: country: GB🇬🇧

❓ World of Work

Environmental activist – what to do with the waste material (cookie biscuit) and its comparative volume to the rock sample.

World of Work Dimensions

Context
Uses two contexts (cookies and mining) legitimizing the WoW afterwards, what might cause a gap.

Role
Student remains in the student role and does not empathize a profession

Activity
Proceedings are an analogy of ore mining asking the students to perform alike.

Product
Report for the directors of the mining company

Related profession
Mining engineer Mineral processor

Figure 3. Chocolate Chip Mining[3]

The activity consists of two parts:

- Part 1 Mineral processing. This is a practical activity which should have a wide appeal. It uses the problem of mining chocolate chips in a biscuit as an analogy for the difficulties involved in developing mineral resources.
- Part 2 Copper mining. This is a data-analysis exercise which is designed to show the real-life importance of the analogy used in Part 1.

Let's look at the four characteristics that are distinguished for the dimension World of Work.

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[3] http://www.fisme.science.uu.nl/toepassingen/22016/

Context	The activity Chocolate chip mining, has two parts and is set in two contexts. The overall context is (the environmental impact of) copper mining. This is briefly mentioned in the introduction of part 1 Mineral processing. No pictures of mining are used in this part. The issue discussed in part 1 is 'mineral processing' set in the context of chocolate chip cookies. In the information for the teacher we read: '*It uses the problem of 'mining' chocolate chips in a biscuit as an analogy for the difficulties involved in developing mineral resources.*' In the student text, the analogy between mineral processing and mining chocolate chips is the main structure of the lesson. For example the text with figure 1 – a picture of chocolate chip cookies - reads '*A typical 'rock' sample*'. The wider context of copper mining, although authentic, is probably not a professional setting that is very near to students of the target group. It is introduced in detail after students do part 1 mining the chocolate chips.
Role	In part 1 the student is explicitly attributed a specific professional role: 'You are a research scientist for a mining company'. The professional setting is also specified: 'You work in a laboratory' as well as the main task connected to the role 'investigate methods for getting useful minerals from rocks'.
Task	The task in part 1 finding and using a method for seperating the chocolate chips from the cookie, is an analogy of the real task of mineral processing. The task is described in terms of a 'research brief' – in an analogon of a professional template. Only terms from the professional field of mineral processing are used. The objects that students use (chocolate chips, cookies, etc.) are referred to in terms like 'dark brown valuable mineral' (chocolate), 'rock sample' (the cookie), 'waste' (cookie crumb), 'mining', 'separating' , 'extracting' and 'investigating' (the activities students do). This helps connecting what students do, to the world of work. Note: The tasks of 'mining the chocolate', which is presented in an open form, is very suitable for inquiry learning (see IBL characteristics)
Product	Report for the directors of the mining company

The guidelines

In this document[4] we describe guidelines for teachers and teacher trainers for (re)designing IBST-oriented classroom materials using workplace contexts. This document is supposed to help teachers and teacher trainers to understand why and how *mascil* tasks support IBL and how they connect to the World of Work (WoW). In addition, it shows how teachers can select and adapt *mascil* tasks or other tasks (textbook, projects, etc.) to their needs and those of their students for promoting IBL and connecting to WoW contexts.

An important aspect of the guidelines is also to understand how to redesign a structured textbook task. Often, it is not necessary to start from scratch when designing tasks that fit the characteristics of *mascil*. The most common starting point is a textbook problem situated in a (rich vocational) context. That's the reason why we describe a small set of ideas to work with redesigning tasks:

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[4] http://www.fisme.science.uu.nl/en/mascil and Appendix 1

From a structured task to a task supporting IBL	• Look for the 'real problem' within the context. Take this as the focal point for redesign • Create opportunities for students to become owner of the problem and a solution strategy • Skip sub-questions • Scaffold students' inquiry process with a lesson plan (introduction, process support and final goal need more attention compared to a structured task) • Provide guidelines about the final evaluation
Connect to the WoW	• Explore the context and try to relate this to the WoW • Think of a workplace practitioner and a workplace activity • Determine a product connecting to the WoW for an audience
Stimulate cooperation and communication	• Ask for products that can be presented or discussed • Make sure the task asks for cooperative work (e.g. sharing of responsibilities) • Organize peer feedback

Finally, as a warning towards the teachers: be aware of the changing role of the task in the learning process of the students. In addition to content-related goals, the new task aims at developing process skills. In some cases this might be at the cost of attention for content knowledge. In other cases it might offer opportunities to deepen content knowledge, or to better assess students' abilities.

Results

In this periode of time (month 7-9, and actually also continued in the task3-period 10-15) we were able to clarify the core concepts of both IBL and WoW, and work towards a database with examples and guidelines to work with the tasks in the classroom.
Those ideas were developed in close relation with WP4 (Professional development) and WP5 (e-learning). Actually, if you look from a distance to the Mascil objectives the Professional Development should have the main focus, tasks are a means to implement the PD.

Further Work

This phase in the work of Mascil was very important for building the underpinning concepts, but this is not ready. Both within the project teams (WPs) and in discussion with other European groups we have to come to richer details to get effective professional development.

Task 3 - Piloting and reviewing materials

In month 10 to 15 we investigated if the *mascil* Framework (Figure 2) was clear enough and if the collected materials are well suited for the work in the classroom. In this experiment we have worked with teachers from lower and upper secondary education, and occasionally with teachers from primary education (most tasks collected are suited for secondary education).

Our main focus was to see if the central concepts (IBL and WoW) are clear to teachers (and other people involved), and also to see if the guidelines have to good flow (a balance between practical issues but also some more theoretical background).

Both in the Netherlands and with the partners that were mentioned (in the DoW) to support us with this task we piloted the following tasks:

- Chocolate Chip Mining
- Brine
- Parking problem
- Pottery
- Drug concentration
- Horticulture

A format was developed[5] to get feedback on the results of working with the classroom materials. Another method was to ask all *mascil* partners to make a Top 3 of *mascil* tasks that best fit their needs (Figure 4).

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[5] http://fd8.formdesk.com/universiteitutrecht/masciltask_en

Figure 4 - The 'Top 3 method' for choosing the best mascil tasks

We were happy to get a very good response to this task for all partners, because this means that the partners have discussed this issue in their teams and that this also means that the repository of tasks becomes more familiar to all people involved and that everybody can make choices which materials fit best to their needs.

Core set of materials

While working on this task 3 we came to the conclusion that it should be wise to have a 'core set' of materials that show the *mascil* characteristics in a representative way, evenly spread in:

- Disciplines; at least math – science
- Spread in age range/school level
    - primary (12-)
    - lower sec 12-16
    - upper sec 16+
- Duration
- Tasks from as many partners as possible
- Usable/used in Toolkit/guidelines (WP4,5)

Results

We finalized this task by:

- publishing the final version of the (re)design guidelines, ready for translation to other languages;
- publishing the core set of *mascil* tasks where partners have to choice to translate at least 15 of those to their own language;

Task 4 - Initial material package for teachers

In this task we had the opportunity to discuss the issues together with our partners (WP345 during a working session in March 2014; and all partners in the Innsbruck meeting in May 2014). We have three questions to answer in this Task 4:

1. Is the connection with WP4 and WP5 strong enough? It makes no sense to have a classroom task repository that is not strongly connected to the Professional Development Toolkit (and e-learning). Did we succeed to make this connection?
2. Do we have enough tasks that have a low barrier to be used by 'less experienced' teachers?
3. What is the connection with the National websites? Are the materials going to be used on a national level?

Question 1. Is the connection with WP4 and WP5 strong enough?

What we did to realise a strong connection is to use examples of classroom materials (already in the repository) as examples in the mascil (re)design guidelines, in the PD toolkit and in the e-learning environment. This was not difficult, because we could build on the same core principles (for example in the area of the WoW the concepts about context, role, task and product). If you look at the main questions in the PD toolkit, it is easy to see that this connection has been made.

Question 2. Do we have enough tasks that have a low barrier to be used by 'less experienced' teachers?

We see differences in the use of IBL tasks between countries. Roughly speaking the North-West countries are used to a 'more open' structure of tasks, while in the South-East there is more structure. These are cultural differences and we think this can be also be the strength of this cooperation.

In order to deal with the differences we decided to define a *mascil* core set' of classroom materials, where every country/partner can find the best examples of both IBL and WoW tasks (see Figure 5).
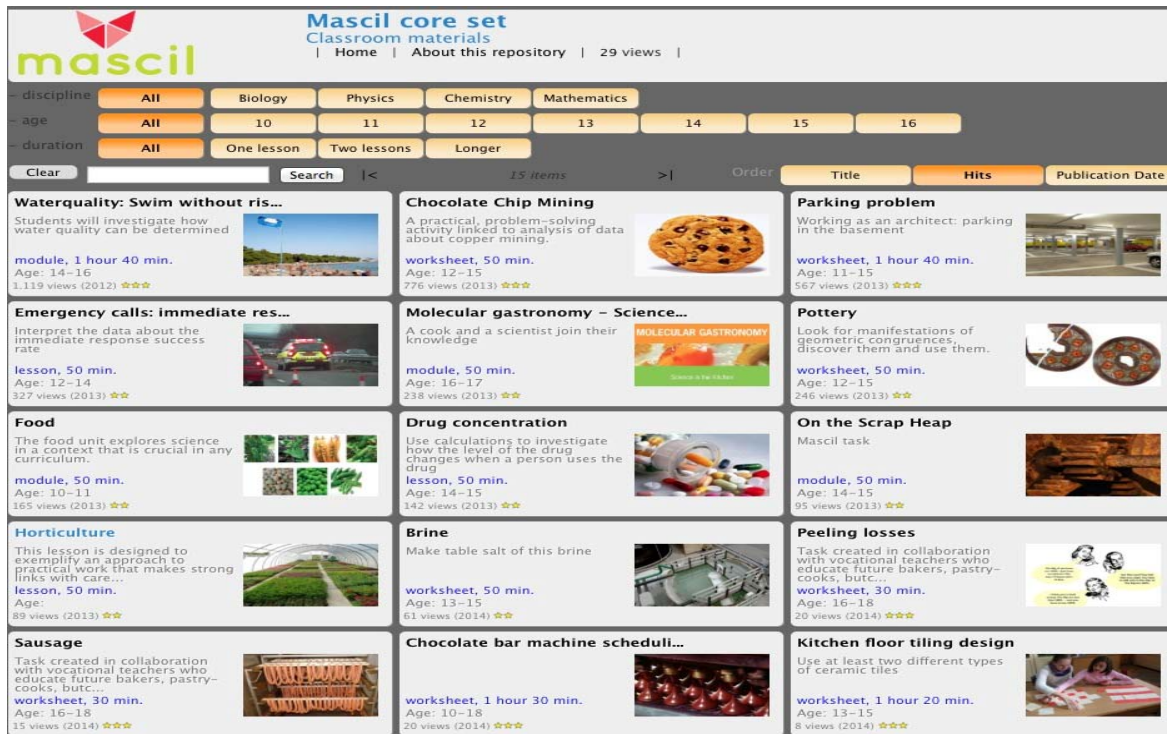
Figure 5 - The *mascil* core set of classroom materials

At the moment we finalize the actual content of every task, including lesson plans, additional information, exact use of video, etc.

Question 3. What is the connection with the National websites?

For reasons of sustainability we decided that the national websites are very important, and that the *mascil* partners are responsible for selecting, adapting and translating from the *mascil* core set of materials. Currently we work with this model:

- All *mascil* tasks will be placed in the central *mascil* database;
- Every task will have a minimum set of metadata[6] (for example 'title', 'abstract', 'target group', etc., as described in Appendix 1) to let the search engine do the important job to show the tasks that fit the actual need. This minimum set of metadata will be in english for all *mascil* tasks;
- The complete set of metadata of the core set of classroom materials will be translated in all languages involved, in order to have those examples as part of the professional development in subsequent countries.

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[6] See http://fd8.formdesk.com/universiteitutrecht/mascil_new_tasks to see an overview of metadata involved.

- Of course new tasks can be added and it is a decision of the *mascil* project if we need additional tasks added to the core set, or that the growth of the amount of mascil tasks will be distributed across the countries.

Results

In June 2014 the materials and guidelines were sent tot the partners to be translated. In the next report we will include the analysis of this work flow.

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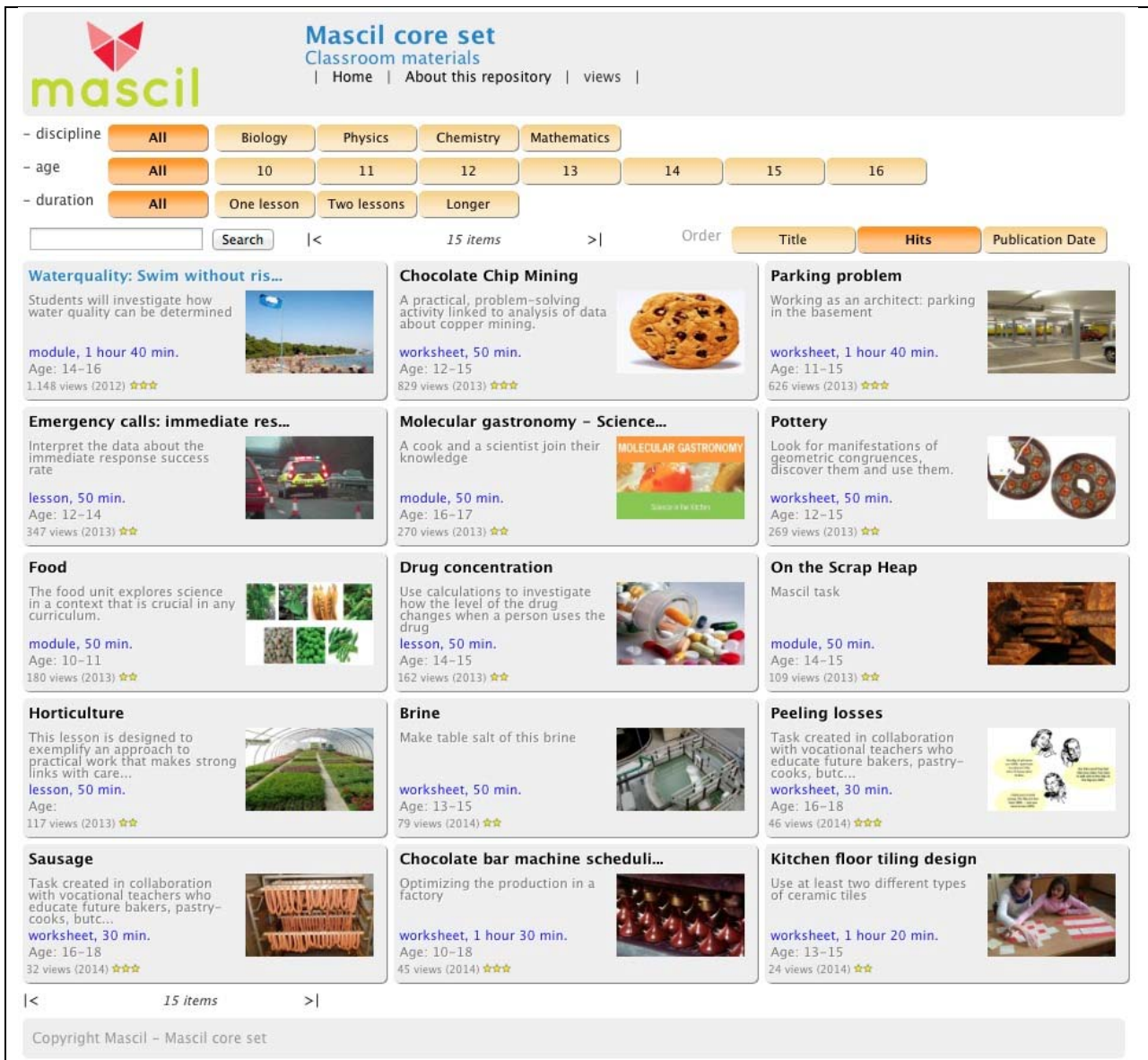
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4. Appendices

You will find two appendices in this document:
- Appendix 1: Overview of the classroom materials
- Appendix 2: (Re)Design Guidelines

5. Appendix 1: Overview of the classroom materials and their metadata

Screenshot of the current core set of materials (www.mascil-project.eu)

Below you find the set of metadata with each of the classroom materials.

Person Name

Name of the person who adds (is responsible for) this example to the *mascil* collection

Person E-mail

E-mail of the person who adds (is responsible for) this example to the *mascil* collection

Title

English title of the activity/materials (e.g. "Amberhavn: new bus network")

Original title

Optional, title in original language

Author

Author name(s) who developed the materials

Project

Project name and/or Publisher name

Url

Web address of the materials

Creative Commons, Copyright

Can the materials be used freely throughout Europe, e.g. under the restriction of Creative Commons (share-alike)

Abstract

200 words (Goal of the task, Describe what students have to do (present, explore, experiment, etc.)

Target Group: age range

E.g. 11-15 years

Level and/or type

Primary, Secondary, Vocational, other remarks about level/type

Discipline

You can choose more than 1 option
Biology
Chemistry
Engineering
Mathematics
Physics
Other:

Key Concepts

A refinement (sub areas) of the disciplines mentioned (also cross-discipline knowledge areas).

Duration

Number of lessons (each lesson is 50 minutes)
One lesson (50 minutes)
Two lessons (about 100 minutes)
Three to five lessons (about 2 hours to 4 hours)
Six to ten lessons (about 5 to 8 hours)

Primas Inquiry Learning dimensions

If possible, check this list used in Primas (more options possible)
Exploring situations
Planning investigations
Experimenting systematically
Interpreting and evaluating
Communicating results
Inquiry Learning, additional comments
Comment on: What makes this activity inquiry learning?

World of Work

What makes this activity related to the world of work?

Related professions

If possible, please mention related professions

Potential for Professional Development

Please reflect on the possibilities to use this example for professional development

Experience with the classroom materials

Experiences of the author, project, others with using the materials. If available: article, etc.

Final remarks

Open question

6. Appendix 2: (Re)Design Guidelines

This is de document that has been developed in month 1 to month 17 of the *mascil* project. This document will be translated to all languages involved in the *mascil* project.

(Re)Design Guidelines

Guidelines for teachers for developing IBST-oriented classroom materials for science and mathematics using workplace contexts

**Connecting inquiry-based learning (IBL)
in mathematics and science
to the World of Work (WoW)**

version 0.96
Date: 4-6-2014

Colophon

Title	MaScil WP3 – Guidelines
	Guidelines for teachers for developing IBST-oriented classroom materials for science and mathematics using workplace contexts from industry
Coordinator	University of Education Freiburg
	Prof. Dr. Katja Maaß
Website	www.mascil-project.eu
Authors	Michiel Doorman, Sabine Fechner, Vincent Jonker, Monica Wijers

Versions

20140604	0.96
20140512	0.91
20140428	0.9
20140320	0.8
20140312	0.7
20140306	0.6
20140224	0.5
20131204	0.4
20131031	0.3
20131023	0.2
20130715	0.1

Introduction

In this document we describe guidelines for teachers and teacher trainers for (re)designing IBST-oriented classroom materials using rich, vocational workplace contexts. This document is supposed to help teachers and teacher trainers to understand why and how *mascil* tasks support IBL and how they connect to workplace contexts (the World of Work, WoW). In addition, it shows how teachers can select and adapt *mascil* tasks or other tasks (textbook, projects, etc.) to their needs and those of their students for promoting IBL and connecting to WoW contexts.

Mascil aims to promote a widespread use of inquiry-based science teaching (IBST) in primary and secondary schools. The major innovation of *mascil* is to connect IBST in school with the World of Work, making science more meaningful for young European students and motivating their interest in careers in science and technology. To achieve these aims, *mascil* collects and publishes examples of classroom materials for inquiry in rich vocational contexts in close collaboration with all *mascil* partners (see: www.mascil-project.eu).

The mascil Framework

Inquiry based learning (IBL) aims to develop and foster inquiring minds and attitudes that are vital in enabling students to face and manage uncertain and quickly changing futures. Fundamentally, IBL is based on students adopting an active, questioning approach. This approach is central to the *mascil* project. In the *mascil* Diagram we summarize the aspects of IBL and the connections to World of Work that constitute our framework for (re)designing classroom tasks (Figure 1).
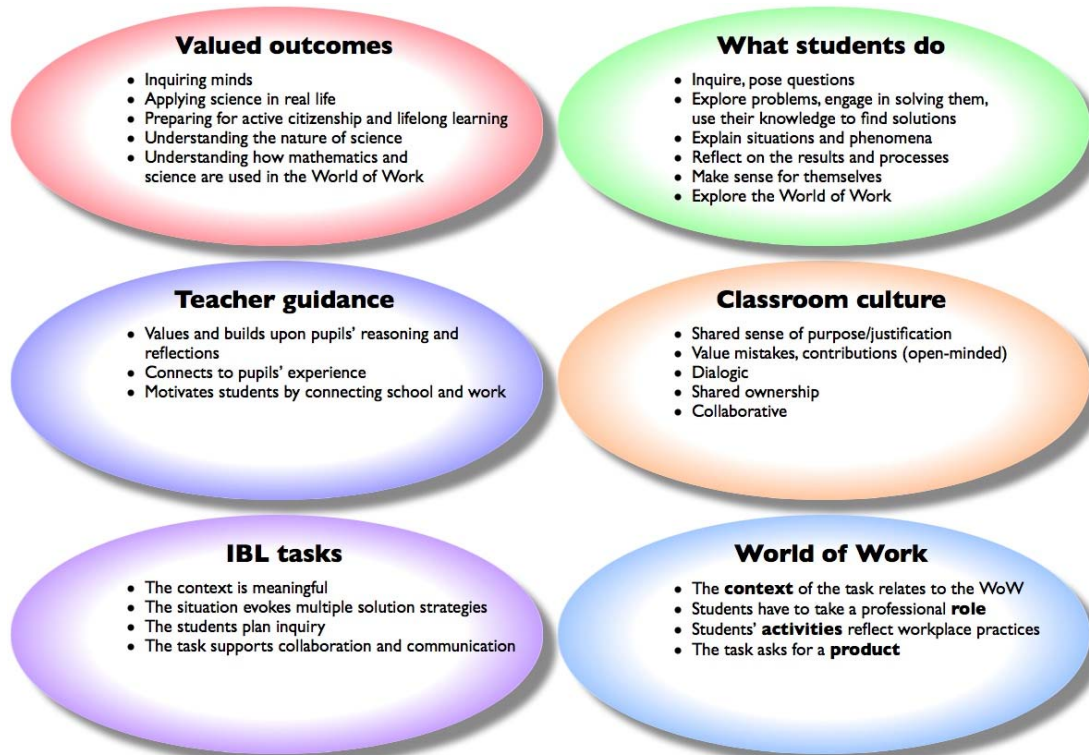
Figure 1: The *mascil* Framework

Some of the characteristics in this framework apply to values and goals of teaching and learning processes in science and mathematics education. The 'IBL tasks' and the 'World of Work' characteristics apply directly to the tasks (materials) used in classrooms. These will be discussed in this document.

In the cloud 'IBL tasks' we distinguish four criteria for tasks that support inquiry-based learning[1]. When students learn by inquiry they explore situations, pose questions, plan investigations, experiment systematically, interpret and evaluate, and collaborate and communicate results. These processes are supported by tasks that are cast in – for students – **meaningful situations**. It might even be the case that such a situation is presented to students without mentioning the main problem that needs to be solved. This meaningfulness allows them to question the situation and to think of ways to tackle possible problems without using standard solution procedures.
When students connect the task to a standard solution procedure, their processes of inquiry will be limited. Consequently, the task should have the potential to evoke **multiple solution strategies**. This is a characteristic of tasks that is highly dependent on the learning history and achievement level of the students that work with the task.

The task does not guide the students along the inquiry process by providing all sub-questions that need to be answered for solving the main problem. The task allows students to (initially) **plan** or think of the process of **inquiry** by themselves.
Finally, the task supports **collaboration and communication**, for instance by providing information of how to distribute work, or by including the need for a presentation of results.

In the cloud 'World of Work' four dimensions of how tasks can be connected to the World of Work are presented: Context, Role, Activity and Product[7].
The **context** in which the task is set relates to the WoW. This relation can be very strong if an (authentic) practice from the WoW is used as the rich context for learning. It should provide a clear purpose and a need to know.
The relation between the context and the WoW may also be weak, if for example the task is set in the context of the WoW, but this context is just a 'superficial wrapping' of the task, and does not remain important when working on the task.
The **activities** students do in the task are related to authentic practices from the WoW. The activities can be more or less similar to activities actually carried out by workers in the workplace. Also, the ways of working reflect characteristics of daily work, for example teamwork, division of labour/tasks etc. The activities should have a clear purpose, involve authentic problems and reveal how mathematics and science are used. The focus in the activities is on students using mathematics and science in ways and in contexts related to the WoW. If students' activities are very similar to typical problems in textbooks for mathematics and science, the connection between activities and WoW is weak.
Within the task students are placed in a **professional role** fitting the context of the task. In some sense students step out of their role as a student.
The outcome of the task is a **product** made by the students in their role as professionals, meant for an appropriate audience. The product is similar to real products from the WoW.

For a task to be strongly connected to the WoW, its relation to the WoW on the dimensions context, role, activities and products should be explicit, well aligned and clear to the students. Not every task will have a similar emphasis on each of these four dimensions, but for a strong connection with the WoW these dimensions need to be taken into account in the actual (re)design of tasks for students.

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[7] A more detailed description can be found in Deliverable 1 and on the *mascil* website.

Guidelines for (re)designing IBST tasks connected to the World of Work

The point of departure for designing *mascil* tasks consists of the national curricula for the science disciplines and mathematics. It is important that the tasks fit the goals of the curriculum and that appropriate content knowledge is addressed. As discussed in the theoretical background, using contexts and authentic practices in IBST does not cause a decrease in content knowledge and understanding if the tasks are carefully designed.

Characteristics of tasks for IBST

First of all, the tasks that teachers give to the students have a major influence in determining the learning that takes place. In this section we describe guidelines for (re)designing tasks that promote inquiry-based learning. However, the resulting written task does not per se promote inquiry by students, since teachers may present an 'IBL' task in a closed and structured way, thus removing the IBL characteristics. The reverse is also true: some teachers

may present a task that can be seen as closed and non-IBL in a way that promotes inquiry. Taking this into consideration, tasks for IBST will have the following characteristics:

1. Tasks support inquiry by students

To provide students with optimal opportunities for exploration, tasks should not be too structured in advance. In many textbooks for mathematics and science, tasks are divided into smaller sub-tasks to guide students smoothly along all possible problems they might confront. In IBST it is the student who gets the opportunity to think of how the problem can be structured and divided into smaller problems. This fosters inquiry by students and ownership of the problems that need to be solved to fulfill the task. The PRIMAS project formulates advice for teachers on how to deal with unstructured problems (see Table 1).

IBL Teaching strategies	Suggested questions
Allow students time to understand the problem and engage with it Discourage students from rushing in too quickly or from asking you to help too soon.	• *Take your time, don't rush.* • *What do you know?* • *What are you trying to do?* • *What is fixed? What can be changed?* • *Don't ask for help too quickly – try to think it out between you.*
Offer strategic rather than technical hints Avoid simplifying problems for students by breaking it down into steps.	• *How could you get started on this problem?* • *What have you tried so far?* • *Can you try a specific example?* • *How can you be systematic here?* • *Can you think of a helpful representation?*
Encourage students to consider alternative methods and approaches Encourage students to compare their own methods.	• *Is there another way of doing this?* • *Describe your method to the rest of the group* • *Which of these two methods do you prefer and why?*
Encourage explanation Make students do the reasoning, and encourage them to explain to one another.	• *Can you explain your method?* • *Can you explain that again differently?* • *Can you put what Sarah just said into your own words?* • *Can you write that down?*
Model thinking and powerful methods When students have done all they can, they will learn from being shown a powerful, elegant approach. If this is done at the beginning, however, they will simply imitate the method and not appreciate why it was needed.	• *Now I'm going to try this problem myself, thinking aloud.* • *I might make some mistakes here – try to spot them for me.* • *This is one way of improving the solution.*

Table 1: Tips for dealing with unstructured problems [8]

2. Tasks allow for multiple solution strategies

It is important that students learn to think about what they already know and what they do not know. Questions (posed by the teacher or the textbook) often point at one

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[8] Source: http://www.primas-project.eu/artikel/en/1044/Tackling+unstructured+problems/

solution or address only a specific aspect of the problem. In IBST the question is posed in a relevant and rich problem situation that is meaningful for the students. What is meaningful for the students depends on their learning history and their familiarity with the context. The richness of the problem refers to a problem that does not evoke one method for solving it. Part of the job for students is to clarify the question and to find a procedure for answering it. In this process, students try to model and solve the problem using representations, relationships or ideas. Such activities are important for students to foster creativity and experience modeling cycles. Tips for supporting student-led inquiry from the PRIMAS project9 are:

- Introduce the situation first, then ask students to identify problems
- Stimulate simplifications and representations of the problem
- Review the representations students use
- Let students further analyze and solve the problem(s)
- Stimulate students to communicate and reflect on their different approaches
- Review the processes that students have been through

3. Tasks stimulate collaboration and communication

In IBST the tasks stimulate collaborative work and ask for answers, solutions or products that are communicated with others through, for instance, reports, presentations or posters. These products also enhance the connection to the World of Work (see fourth characteristic in next section). For such products it is important that students are aware of the inquiry-related goals of the task in a mathematics or science classroom (e.g. to become more able to explore, plan, experiment, evaluate, collaborate, …). These goals can be communicated in advance or through organizing (peer) feedback on products or presentations; for example by presenting and discussing well-prepared sample work from other students or by asking students to assess each other's work to identify, make explicit and use inquiry-related criteria for evaluation.

Characteristics of tasks that connect to the World of Work

Tasks that fit the aims of mascil are tasks that (i) connect to curricular content goals, (ii) support IBL and (iii) are set in rich vocational contexts. The connection to the World of Work is ensured by the following characteristic: students are given a professional role, as 'workers' in a workplace, and they perform activities that are similar to activities actually done by workers. These activities have a clear purpose and reveal how mathematics and science are used in work settings. A product for an audience is the result. These characteristics, that also guide the design process, are illustrated below in more detail.

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9 Source: http://www.primas-project.eu/artikel/en/1260/Student-led+inquiry/

1. Rich vocational contexts

Rich vocational contexts give students insights into the usefulness (purpose and utility) of mathematics and science in the WoW. The mathematics or science in the task should of course also fit your curricular goals. To find suitable rich vocational contexts several actions can be undertaken. Before you start you may orient yourself by:

- Asking your students what types of profession they are interested in;
- Finding out if any contexts related to the WoW are already used in your teaching materials;
- Using the *mascil* framework (Figure 1 and 2) to get a better understanding about the dimensions of both IBL and WoW.

To find out in what ways mathematics and science are used in workplaces, you may want to:

- Talk to professionals in your personal network
- Talk to or visit a vocational teacher at your school or in your region
- Read journals for professionals
- Visit websites of companies and look for educational materials
- Visit a specific workplace

Once you have found a suitable context and identified authentic practices to use, you can start to (re)design teaching materials. This is a cyclic process in which context, underlying content knowledge and possible student activities influence each other. You may want to:

- Provide students with the opportunity to explore the professional context of the task: what are typical activities, tools, data, language outcomes, products, problems of this workplace? This may be done e.g. by showing as part of the task a video or photos or artefacts from the workplace, inviting professionals to the classroom, having students visit a workplace or a website of a company;
- Use the activities from the authentic practice (and the related mathematical and scientific concepts) as a starting point and as the backbone for the design;
- Use artefacts and tools from the workplace in the design;
- Make adaptations (e.g. simplify, model, build in scaffolds) to make the authentic practice accessible for students. Beware of losing coherence and authenticity when re-contextualising, it may lead to contrived instead of authentic activities.

2. Giving students a professional role

In the teaching materials, try to give students a professional role that fits the context of the task, not only to ensure engagement with the task, but also to have students experience the purpose of the activities they perform.

- This role can be very specific (e.g. an architect) or more general (e.g. a scientist). A job description, the workplace setting or a specification of the work to be done, may be described in the task.
- You may want to have the ways student work on the task reflect the ways of working of professionals e.g. working in teams[10], division of labour, working within constraints, using authentic artefacts like tools, instruments and data.
- Note: Make the professional role as concrete and specific as possible. For example, if an activity fulfils all requirements of inquiry learning, we could argue that the role of researcher is prominent in this activity. This is a professional role and so the relation to WoW seems to be strong. For students however this relation may not be as clear as we think. The professional role in this case is often not a specific type of researcher. The same is true for 'engineer' in a design activity. In the teaching materials you may therefore decide to provide students with background materials and resources about this profession.

3. Have students perform workplace activities

Your task may contain several activities that students need to carry out. When designing these activities consider the following:

- Make solving an authentic workplace problem, using *known* concepts, skills and procedures from mathematics and science, the central activity in the design. All the other activities need to have a purpose with respect to this central problem;
- Have student activities be similar to (or analogies of) actions, processes or procedures used in workplaces. Some simplification or scaffolding may be needed, but beware of losing authenticity and the open, inquiry based character of the task.
- Make sure that the activities fit the context and the role.
- Use workplace language where possible and connect this to the disciplinary language;
- Present activities in such a way that they provide students with valuable opportunities to use knowledge of mathematics and science in the way it is applied in professional settings. You may use authentic artefacts like research briefs, memos, schemes or task descriptions to present the activities in an authentic way.

4. Targeting products connected to the World of Work

When designing the task, work towards a concrete product as outcome. This reflects the nature of workplaces, which generate explicit final products. The product can take

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[10] This relates to the characteristic 'stimulation, collaboration and communication' that is discussed in the previous paragraph.

many shapes, for example, it may be an object or a report or an advice. Consider the following:

- The intended product should fit the context, role and activities;
- Make sure that the product has an audience for whom the product is useful. If the audience is not immediately clear from the activities, make explicit for the students who the audience is. A clear audience, as part of the community of practice, will help define the product and its specifications;
- Have students include an appendix, a brief, a memo or a log in which they show or explain the way they used math or science (the process) to address and solve the problem;
- Include suggestions and/or instruments for reflecting on and evaluating process and product. An example of such a list of criteria can be found in figure 2[11].

JUDGING:

Among other things, the following points are important for the jury:

- How complete the answers for the various parts are;
- the representation of calculations and the method used
- the efficency of the proposed schedules
- The use of math;
- The argumentation used and how choices that have been made are justified;
- The depth to which the various assignments have been answered;
- The style of presentation: form, legibility, (copyable) illustrations etc;
- Originality and creativity.

Figure 2: An example of a list of criteria to evaluate process and product

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[11] Copied from the *mascil* problem 'Container logistics': http://www.fisme.science.uu.nl/toepassingen/00810/

Guidelines for redesigning

Redesigning a structured textbook task

Often, it is not necessary to start from scratch when designing tasks that fit the characteristics of *mascil*. An easy-to-find starting point is a textbook problem situated in a (rich vocational) context. The activities presented to the
students will in that case be typical textbook problems: highly structured, closed, divided in sub-problems, with a lot of guidance. If this is the case you may keep the setting (the context), but change the activities. This can be done by opening them up, stating a purpose, describing a meaningful situation that 'naturally' incorporates and evokes questions, or starting with an authentic overarching problem in order to support inquiry-based learning.

Connecting an IBL task to the World of Work

The starting point for a *mascil* task may also be an existing IBL task for mathematics or science that is not yet related to the World of Work[12]. In this case it is often possible to add contextual information from the WoW, to formulate activities for the students that are related to similar authentic practices from the WoW, to give students a professional role and to define an appropriate product.

Guidelines for (re)design

- From a structured (textbook) task to a task supporting IBL
  - Look for the 'relevant and meaningful (for the students) problem' within the context. Take this as the focal point for redesign
  - Create opportunities for students to become owner of the problem and a solution strategy (the problem gives rise to multiple strategies)
  - Skip sub-questions and have students plan or be involved in planning the inquiry
  - Scaffold students' inquiry process (e.g. with a lesson plan including an introduction of the problem situation and process support)
  - Provide guidelines about the final evaluation
- Connect to the WoW
  - Explore the context and try to relate this to the WoW
    Note: be aware that it is not always possible to connect an existing task to a practice from the WoW in an authentic way.
  - Think of a workplace practitioner and a workplace activity that fit the task (as a backbone for the (re)design)

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[12] This type of tasks can be found on the PRIMAS site www.primas-project.eu

- o Use artefacts, tools and language from the workplace where possible and adapt and connect this to disciplinary use
        - o Make the professional role as concrete as possible
        - o Determine a product connecting to the WoW for an audience
- Stimulate collaboration and communication
        - o Ask for products that can be presented or discussed
        - o Make sure the task asks for collaborative work (e.g. sharing of responsibilities)
        - o Organize peer feedback

Finally, be aware of the changing role of the task in the learning process of the students. In addition to content-related goals, the new task aims to develop process skills. In some cases this might be at the cost of attention for content knowledge. In other cases it might offer opportunities to deepen content knowledge, or to better assess students' abilities.

Examples

1. Calculating Body Mass Index[13]
This example shows two versions of a task. The first one is a highly structured version of the task that guides the students along all the steps needed to discover the mathematics behind a Body Mass Index calculator. The sub-questions 'do the thinking' for you. In the second version of the task, structuring is the responsibility of the students.

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[13] Drawn from the PRIMAS project:
http://www.primas-project.eu/artikel/en/1044/Tackling+unstructured+problems/

Calculating Body Mass Index

This calculator is used to help adults find out if they are overweight.

Body Mass Index (BMI) Calculator
Enter values for height and weight.

Height: 1.83 metres
Weight: 80 kilograms
BMI: 23.9
You are in the Ideal weight category

Body mass index (BMI) is measure of body fat
that applies to adult men and women.

1. Fix the height at 2 metres - a very tall person!
Complete the table below and draw a graph to show your results.

Weight (kg)	60	70	80	90	100	110	120	130	140
BMI									

(a) What is the largest BMI for which someone is underweight?
(b) What is the smallest BMI for which someone is overweight?
(c) When you double the weight, what happens to the BMI?
(d) Can you find a rule for calculating BMI from the weight?

2. Fix the weight at 80 kilograms and try varying the height.

(a) When you double the height, what happens to the BMI?
(b) Can you find a rule for calculating BMI from the height?
(c) Draw a graph to show the relationship between the height and the BMI.

First version of Body Mask Index (highly structured)

Calculating Body Mass Index

This calculator shown is used on websites to help an
adult decide if he or she is overweight.
What values of the BMI indicate
whether an adult is underweight,
overweight, obese, or very obese?

Investigate how the calculator works
out the BMI from the height and weight.

Body Mass Index (BMI) Calculator
Enter values for height and weight.

Height: 1.83 metres
Weight: 80 kilograms
BMI: 23.9
You are in the Ideal weight category

Body mass index (BMI) is measure of body fat
that applies to adult men and women.

Note for pupils: If you put your own details into this calculator, *don't take the results too seriously!* It
is designed for adults *who have stopped growing* and will give misleading results for children or
teenagers!

Second version of Body Mask Index (structure is responsibility for student)

2. Drug Concentration

These two versions of a similar task show how a task can be redesigned to support IBL and to connect to the World of Work. The second version of the task does not provide the sub-questions that guide the students along the solution process. In addition, it asks for a clear product that provides a purpose and connects to a workplace practice. The flyer can be used to have the students give each other feedback on the result of the activity.

A structured version of the task

A patient is ill. A doctor prescribes a medicine for this patient and advises to take a daily dose of 1500 mg. After taking the dose an average of 25% of the drug leaves the body by secretion during a day. The rest of the drug stays in the blood of the patient.

1. How much mg of the drug is in the blood of the patient after one day?

2. Finish the table.

Day	Mg of drug in blood
0	0
1	1125
2	
3	

3. Explain why you can calculate the amount of drug for the next day with the formula:
new_amount = (old_amount + 1500) * 0,75

4. After how many days has the patient more than 4 g medicine in the blood? And after how many days 5 g?

5. What is the maximum of amount of the drug that can be reached? Explain your answer.

A version for IBL and connecting the task to the WoW[14]

A doctor presents the following details about the use of a specific drug:
- An average of 25% of the drug leaves your body by secretion during a day.
- The drug is effective after a certain level is reached.
- Therefore it takes a few days before the drug that you take every day is effective.
- Do not skip a day.
- It can be unwise to compensate a day when you forgot the drug with a double dose the next day.

N.B. These details are a simplification of reality.

Investigation
- Use calculations to investigate how the level of the drug changes when someone starts taking the drug in a daily dose of 1500 mg with for instance three times 500 mg.
- Are the consequences of skipping a day and/or of taking a double dose really so dramatic?
- Can each drug level be reached? Explain your answer.

Product
Design a flyer for patients with answers to the above questions. Include graphs and/or tables to illustrate the progress of the drug level over several days.

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[14] Drawn from *mascil* task 'Drug Concentration' www.fisme.science.uu.nl/toepassingen/22038

The second version gives less information about how the students will arrive at a final product. Teachers need to think in advance on how to scaffold their inquiry process. An example lesson plan for the IBL activity is:

A sample lesson plan
Lesson 1
10 minutes: create groups & introduce the problem and the working plan and distribute the task
10 minutes: students work in groups on the task
10 minutes: discuss with the whole class whether all groups have an idea how to start and how to proceed. Exchange strategies and make sure that everybody has an idea what is expected.
15 minutes: students work on the task, finish calculations and prepare the building blocks for their flyer.
Lesson 2
20 minutes: students finish their flyer
20 minutes: presentations of a few examples
10 minutes: reflection on the task (and positioning it in further work)

3. Brine[15]

This example provides three versions of a task that show how a structured version of a task can be redesigned into a task supporting IBL by deleting the sub-tasks and having the students themselves think of the equipment that can be used. Finally, the alternative introduction of the task shows how it can be connected to the World of Work by including a workplace practice, providing a practitioner's role and asking for a clear product.

Structured version of the Brines task   **A version of the Brines task supporting IBL**

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[15] Drawn from *mascil* task 'Brines': www.fisme.science.uu.nl/toepassingen/28121/

Worksheet: Purifying a brine

To separate different substances and obtain pure sodium chloride, you have to conduct a two-step experiment. In the first step, the separation technique of *filtration* is used to separate sand and stones from the brine. In the second step, the brine is heated (technique: *evaporisation*) to separate water from the salt (sodium chloride).

Substance: Brine consisting of dissolved sodium chloride unpurified with sand and stones

Material: Erlenmeyer flask, beakers, Bunsen burner, tripod, wire gauze, funnel, filter paper, eye protection

Safety measures: Wear your eye protection!

Task 1
Insert the funnel into the Erlenmeyer flask. Fold a filter paper, place it into the funnel and wet it with some water. The solution is poured into the funnel. Remove the funnel and discard the filter paper.

Task 2
Place the Erlenmeyer flask with the remaining solution onto the wire gauze on top of a tripod and heat it with a Bunsen burner. Wait until all water is evaporated and observe the substance that is left over.
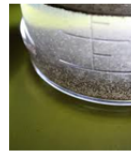
Task 3
Name the properties of the substances that make separation possible.

Task 4
Explain the process involved in the two steps of the experiment on the molecular level.

Purifying a brine

Your task is to purify a sample brine and obtain the pure substance sodium chloride. You only know that the brine is a mixture of sodium chloride, sand and stones in water.

In your group you have to develop an experiment to purify the brine. You will get a sample of the brine and a selection of equipment that you may use to conduct your experiment.

At the end of the lesson you present your experiment and your findings.

For your experiment, you are allowed to use the following equipment:

- Beakers
- Erlenmeyer flask
- Bunsen burner
- tripod
- wire gauze
- funnel
- filter paper
- …

Wear your eye protection!

If you think a different device would be useful, discuss your idea with the teacher!

Follow-up question:

Explain the processes involved in the steps of your experiment on the molecular level.

An introduction to the Brines task that connects it to the WoW

You are an engineer at a water production company. The company pumps water from the ground and cleans it for drinking water. The dirty groundwater tastes salty. Maybe it is profitable to extract salt from it? First questions are: how much salt is in the brine and how to separate the salt?

Your task is to design a process to come up with salt from the brine that might be used in the kitchen and to determine how much salt is in the brine. Write an advice for the company based on your findings.

Format for designing materials

Tasks need to have an attractiv layout and format. In WP6/WP1 a proposal has been made for a *mascil* template for tasks (Figure 3). This format will be delivered (on the *mascil* website) to be used for designing materials within the *mascil* project.

Figure 3: An example template for task-design within the *mascil* project

Theoretical background

The first chapters were written to support the teacher in his daily work. In the current chapter 'Theoretical background' we show that the underlying ideas are grounded in research and relate to the framework that emerged from an analysis of the *mascil* (Mathematics and Science for Life) task collection[16].

Inquiry-based learning (IBL) is defined as being inductive, student-centred and focused on creativity and collaboration (Doorman, 2011). IBL aims to develop and foster inquiring minds and attitudes that are vital for students to face and manage uncertain futures. Fundamentally, IBL is based on students adopting an active, questioning approach. The problems they address are supposed to be experienced as real, they inquire and pose questions themselves, explore problem situations and evaluate results. Learning is driven by open questions and multiple-solution strategies.

Although this model of IBL is student-centred, the learning process is guided and scaffolded by teachers and classroom materials (Hmelo-Silver, Duncan & Chinn, 2007). Our model should not be confused with that of minimally guided discovery methods, where the teacher simply presents tasks and expects learners to explore and discover ideas for themselves (Kirschner, Sweller & Clark, 2006). IBL asks for teachers being proactive: they support and encourage students who are struggling, make constructive use of students' prior knowledge, challenge students through probing questions, manage small group and whole class discussions, encourage discussing alternative viewpoints and help students to make connections between their ideas (Crawford, 2000). This is quite an effort and cannot be expected from teachers in every lesson. A message that teachers should therefore take to heart is: *You don't need to change everything. IBL is not a completely different educational practice, but an essential ingredient of good education.*

IBL is seen to be effective in both primary and secondary education in increasing children's interest and attainment levels as well as in stimulating teacher motivation (Rocard, 2007; Furtak, Seidel, Iverson & Briggs, 2012; Schroeder et al. 2007). IBL motivates students and enhances learning outcomes.

In order to enforce the benefits of IBL and make science and mathematics more meaningful to students rich vocational contexts will be used in *mascil* tasks, to connect mathematics and science to the WoW. Research supports the use of contexts in science teaching. Context-based science education does not lead to a decrease in the development of understanding of science, and has considerable benefits in terms of attitudes to school science and of abilities in solving context-based problems (Bennett,

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[16] See *mascil* deliverable 3.1 on www.mascil-project.eu

Lubben & Hogarth, 2007). The WoW introduces contexts that can be presented as authentic practices, which Gilbert (2006) sees as the most promising model for context-based science education (Prins, 2010; Dierdorp et al., 2010). Research findings show that students experience and understand the functionality, purpose and utility of disciplinary knowledge in the workplace (Ainley, Pratt & Hansen, 2006; Dierdorp, 2010; Mazereeuw, 2013). For this to happen however, it is important that tasks are carefully designed and fit the goals of the curriculum. In the context of work the use of science and mathematics emerges from the activities and tasks of the workplace (Hoyles & Noss, 2010). Therefore the teaching materials should reflect authentic practices and experiences related to the World of Work. Finally, the use of rich vocational contexts asks a lot from teachers. They have to master contextual knowledge and skills as well as connecting content-context knowledge and skills. We do not want to suggest that every lesson should be cast in a vocational context, but the starting point for *mascil* is that these contexts are also an important ingredient of good education.

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