Report from the FP7 project:

Assess Inquiry in Science, Technology and Mathematics Education

Description of the ASSIST-ME assessment methods and competences

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1. Summary and introduction

One of the goals of ASSIST-ME work package 4 was to describe formative assessment methods and competences related to inquiry learning that should be assessed by these assessment methods. The final version of the assessment methods and the competences can be found in this report.

Chapters 2 and 3 will present the definitions of inquiry for the domains science, Mathematics and Technology and the definitions of formative and summative assessment. All these definitions are based on the literature review conducted in work package 2 and they have been elaborated by the project partners from IPN.

Chapter 4 provides the link between the definitions from chapters 2 / 3 and the rest of this report: it is distinguished between (1) ways of data collection about student learning, (2) feedback methods, and (3) competences and sub-competences. An assessment method consists of a way of data collection about student learning combined with a feedback method.

Chapter 5 will provide an overview of different ways of data collection about student learning. There is an endless number of ways to collect data, but these ways are organized in four groups:

- written student data,
- performance - based data,
- oral data,
- electronically collected data.

Chapter 6 will introduce the four feedback methods selected for the ASSIST-ME project. For each of the methods, the principle will be described, followed by a few varieties in use. The four feedback methods are

- Interactions on the fly
- Marking (grading and written comments)
- Self- and peer-feedback
- Structured classroom dialogues and open classroom discussions.

Chapter 7 will describe the ASSIST-ME inquiry platform which was designed to electronically facilitate inquiry learning, electronically collect student data, and electronically provide formative feedback.

Chapter 8 will define the selected competences in the ASSIST-ME project. Each of the competences will have a number of sub-competences subsumed. The competences include:

- investigations in science education
- problem solving in Mathematics education
- engineering design in Technology education
- argumentation

- modelling
- innovation.

Paradigmatic examples that illustrate the formative assessment of specific competences and sub-competences based on data about student learning will be circulated among the project partners and uploaded to the sharepoint by 15th August 2014.

2. Definitions of "inquiry-based education in science, technology and mathematics education" within the ASSIST-ME project

This chapter was written by Silke Rönnebeck and Mathias Ropohl, with additions by Wynne Harlen.

For the work to be conducted in the ASSIST-ME project, a common understanding of what is meant within the project by inquiry-based education in science, technology and mathematics as well as by formative and summative assessment is needed. The following definitions are based on the literature review conducted by WP 2 (see Deliverables D2.4, D2.5 and D2.7). To allow for an operationalization, they had to be as short and precise as possible while at the same time capturing the key features of inquiry-based education within the three domains.

In science education, the process of scientific inquiry involves developing an understanding of scientific aspects of the world around through identifying questions, searching for relevant information, formulating hypotheses or making predictions, planning and carrying out experiments, analyzing, interpreting and evaluating data and results, developing explanations, constructing and using models, engaging in argumentation from evidence and being able to communicate scientifically in different situations and at all steps of the inquiry process.

In technology education, the process of engineering design involves developing an understanding of the nature and principles of design and technology through defining and delimiting a problem, need or desire, identifying constraints and criteria, investigating relevant information, generating and evaluating possible solutions, analysing alternatives, selecting a potential solution, justifying the decision, planning design of prototype, constructing prototype (using suitable tools/materials), testing prototype by collecting, analysing, interpreting and representing data, evaluate prototype against the criteria, reasoning, modifying the design and redesigning if necessary and communicating at all stages of the process.

In mathematics education, the process of problem solving involves developing an understanding of mathematics through describing and understanding mathematical or ‚real world' problems, transferring problems into the ‚mathematical world' (if necessary), exploring problems and making conjectures, identifying what is known and what is unknown, creating, using and manipulating mathematical representations, planning and carrying out a problem solving strategy, making and analyzing connections, evaluating the strategy, the conjectures and the meaningfulness of the results, generalizing and systematizing the results and the specific problem solving strategy and communicating one's actions by using adequate vocabulary/representations at every stage of the process.

3. Definitions of "formative assessment" and "summative assessment" for this project

This chapter was written by Silke Rönnebeck and Mathias Ropohl, with additions by Wynne Harlen and Paul Black.

In this chapter, definitions for formative assessment as well as for summative assessment will be provided. For a comprehensive review on formative and summative assessment in inquiry-based education, see deliverable D2.4 (Bernholt et al., 2013).

The work within ASSIST-ME is based on the principle that, in general, assessment can be used to promote learning and also to evaluate learning. According to their different purposes, however, these two types of assessment differ in certain characteristics which in the research literature are summarized under formative and summative assessment, respectively. The relations between formative and summative assessment as well as their underlying characteristics are shown in figure 1.

Formative assessment is ‘assessment for learning‘ that aims at supporting and improving student learning as it takes place. It has to be designed to support all of the phases of inquiry-based learning as set out in the explanations given above. It is classroom-based, can be at individual or group level as well as criterion referenced. It has a procedural character and can be implemented in many ways: as students conduct activities, they may be helped by immediate question and suggestions to challenge their thinking. On a longer time-scale, data on the achievements made may be collected and interpreted in relation to achievement goals and assessed in the light of student-based criteria. Such data may both indicate the feedback which could be given to help students, individually or collectively, to enhance the learning already achieved, and may also be used to inform decisions about how to reach the next learning steps through the design of new student activities. At all stages there is feedback from teacher to student and from student to teacher (and from student to student into the teaching-learning process). Formative assessment thus has the function of individual and group support but at the same time gives students an active role in all steps of the assessment process.

Summative assessment is ‘assessment of learning‘ with the goal of summarizing, evaluating and reporting learning at a particular point in time. Data is collected and interpreted related to predefined achievement goals (either as a survey or following a student activity) and a judgement is made which is criterion referenced using the same criteria for all students to ensure the comparability of achievement results. The data may also be shared with students to help them develop the ability to review their own work. The process results in a judgment and report of what the student has achieved at a particular time in relation to the goals or standards.

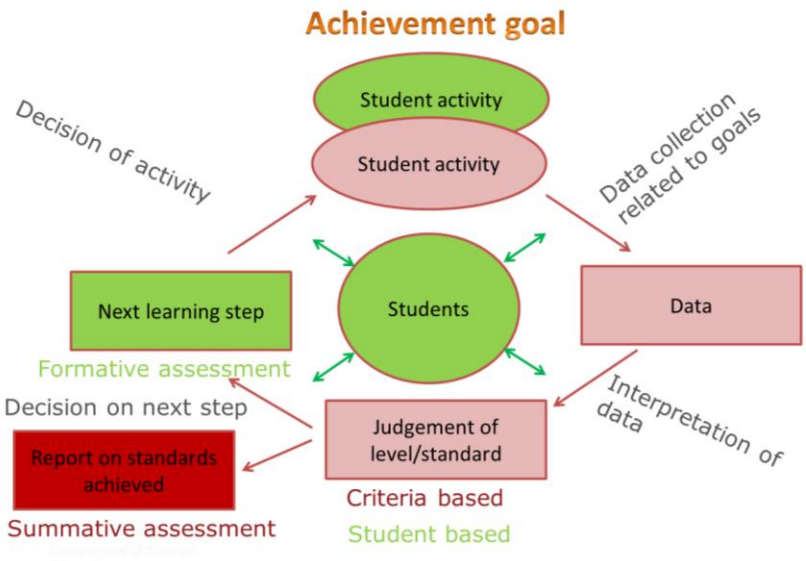

Figure 1: The relation of formative and summative assessment. Taken from Dolin, 2014, based on Harlen, 2013.

Within the ASSIST-ME project, the following three criteria to characterize formative assessment were chosen:

1. Active student involvement in the whole assessment process.
2. The criteria used in the judgment of student activity are student-referenced as well as subject-specific (meaning that the feedback to the student is adapted to the individual student).
3. The immediate aim of the assessment is the identification of further activities that promote the individual students' learning.

4. Link between the definitions to the following chapters

As the model from Harlen, 2013, which is displayed in figure 1, suggests, several steps form an assessment cycle. In the ASSIST-ME project, the aim is not to develop inquiry units and student activities, but to concentrate on the "data collection related to goals", on the "interpretation of the data" and on the "decision on next step". Therefore, the following chapters of this report will concentrate on three elements (compare to figure 2):

- Competences and sub-competences which are relevant in inquiry learning which reflect the goals in the model from Harlen, 2013 which is displayed in figure 1.
- Means of collection of data on student learning
- Feedback methods which reflect both the "interpretation of the data" and the "decision on next steps of learning" in the model from Harlen, 2013. This means that the feedback methods allow both for diagnosis and for interaction / feedback for the learner. The "decision on next steps of learning" makes the difference between formative and summative assessment (see figure 1).

The plane between the axis on data collection and the axis on feedback methods symbolizes formative and summative assessment methods; so an assessment method consists of both a means of data collection and a feedback method.

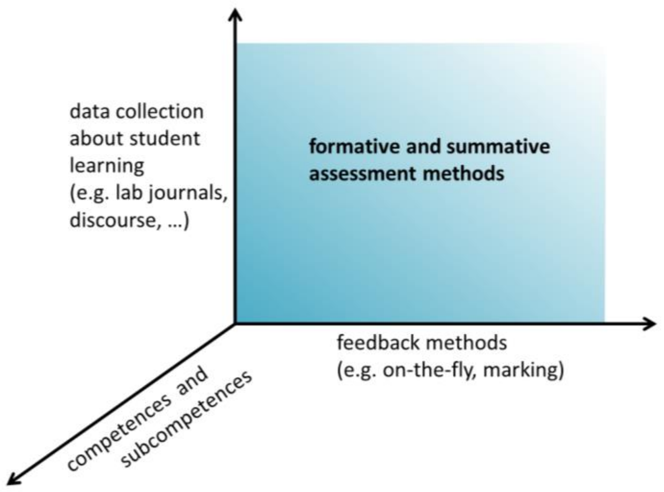

Figure 2: The three elements the following chapters of the report will concentrate on.

Data collection about learning means generating information on students' learning progress. Each of the feedback methods uses this information for interpretation of the data (diagnosis) and for interacting with the learner about his /her learning progress and in order to decide about the next steps of learning. This interaction could take place between the teacher and the student(s) or between peers.

Formative assessment needs both elements: the data collection and feedback methods. However, it does not in every case make sense to distinct between data collection and assessment: when it comes to dialogue - based assessment (for example the student-teacher assessment dialogue (Christensen, 2004)), the two elements are very closely intertwined.

The concrete use of the different means data collection and the different feedback methods will be illustrated by paradigmatic examples. In some of these examples, a part of an inquiry is assessed in the context of a whole inquiry (i.e. the teacher focuses on one part but the student is paying attention to the whole) whereas in other paradigmatic examples, a part of an inquiry is assessed when only that part is being considered (such as presenting some ready-made results to interpret). In some of the examples, only a narrow sub-competence from the field of IBE-relevant competences is assessed whereas in other examples, broader spectrum of sub-competences from the field of IBE is assessed.

5. Data collection about student learning

Before assessing and providing feedback, one needs to collect data about student learning. This data collections needs to be followed by analysis, interpretation, communication, decision making and application of the decisions. There is an undefined number of kinds of data but they are organized in four groups here:

1) Written data about student learning (written data can and will be captured on paper and electronically)
2) Performance - based data about student learning (performance data can and will be captured on paper and electronically)
3) Oral data about student learning
4) Electronically collected data about student learning (as mentioned in the first 2 bullet points the same data that can be collected on a computer or on paper. Here the specific data that can only be captured electronically is described.)

5.1 Written data about student learning (non - exhaustive list)

This chapter will introduce different means of written data collection about student learning. The chapter is based on Bernholt et al. (2013).

Multiple Choice

Multiple Choice items consist of a question and several options which can be chosen as a correct answer. The advantage is that this way of data collection is very fast, objective, and easier to compare and interpret than other more complex assessment methods (Bernholt et al., 2013).

Online tools such as socrative.com provide the opportunity to display the resulting answer pattern from a class graphically. This allows for a discussion in classroom or other means of formative assessment.

Mazur, 1997, lets students solve multiple choice items individually and afterwards ask them to discuss their answers and the reasons for their choice in pairs. Finally, the students answer the same items again.

Written answers to open questions

Written answers here refer to answers on open questions. Open questions require students to formulate the answer themselves; the format may or may not be pre-defined. There will usually be many correct and good solutions (contrary to the multiple choice questions where there is only one correct answer pattern) - so in teaching practice, it will be very important to have clear criteria for the assessment of the answers.

Written assignment

Data from summative tests can also be used formatively! For example, a series of written assignments could be used as a basis for reflection (self-assessment). Black & Harrison (2004), come up with more ideas: students could fill out the end-of topic test in the first lesson of the topic in order to inform the teacher of what they know, what they partly know and what they do not know. Another approach is to discuss the summative tests after returning them to students and discuss specific questions that where causing most problems (Black & Harrison, 2004).

Sketch

Sketches refer to all kind of students' drawings and graphical representations here. As with the open questions, there is a whole variety of correct solutions which makes it important to clarify the assessment criteria.

Poster

Posters are a valuable tool for students to display their work and progress to a larger public. It should be clearly defined what the students are expected to display on the poster, and particularly with younger students, it might make sense to pre-define the structure of the poster and to provide hints and advice regarding the visual appearance.

Concept map, mind map

Both concept maps and mind maps are methods to organize and visualize knowledge.

Concept maps allow students to link key terms to a network-like structure. The links between the key terms are usually labelled as in the example in figure 3. This method is especially valuable to display cause and effect - structures. Concept maps help to assess students understanding of key concepts or to check the progress in understanding key concepts at several times during a treatment (Bernholt et al., 2013).

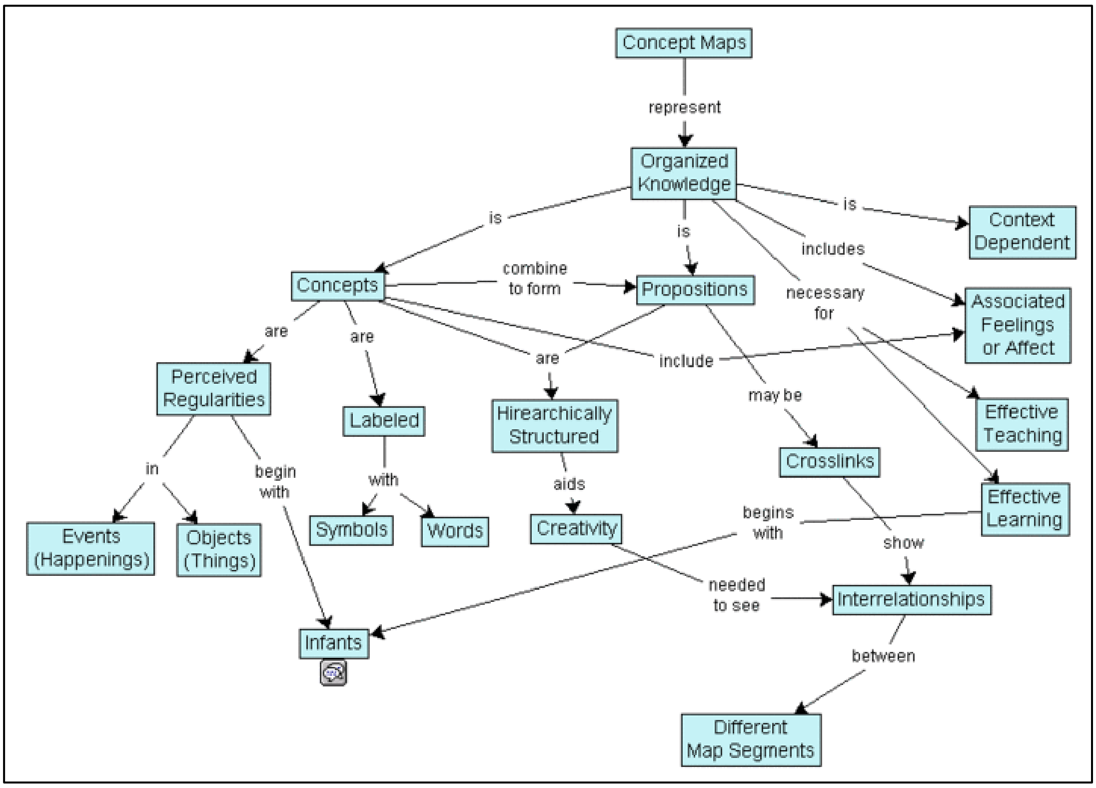

Figure 3: A concept map on concept maps. Taken from http://en.wikipedia.org/wiki/Concept_map#mediaviewer/File:Conceptmap.gif.

Mind maps, on the other hand, start from a central idea and organise related aspects hierarchically. So mind maps are more structured than concept maps.

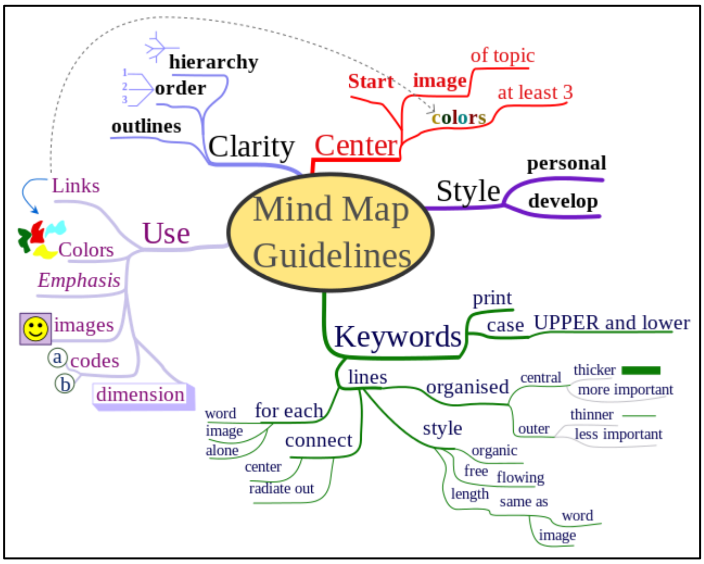

Figure 4: A mind map on mind map guidelines. Taken from http://upload.wikimedia.org/wikipedia/commons/6/66/MindMapGuidlines.svg.

Report (lab report, excursion report, …)

The term 'report' refers to all kinds of written pieces of work that tell about a lab experiment, an investigation, an excursion, a construction task or similar. Reports are very often structured in several sections that give details about the aim and the planning phase, the conduction and the data collection, and evaluation and discussion of the data.

Notebook, lab journal

Notebooks and lab journals are typically used to document ideas and thoughts, concerns, experimental designs or construction plans as well as collected data. These raw materials can be used as a basis to write a more formal report later on.

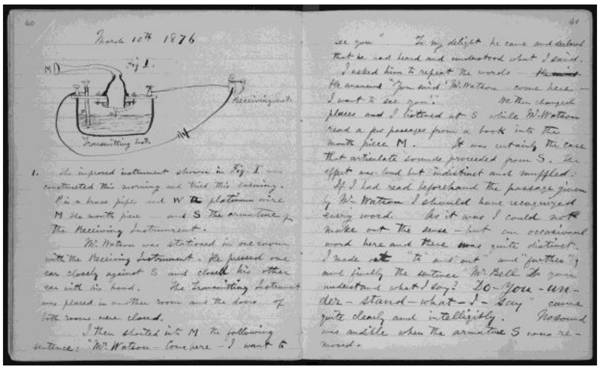

Figure 5: Alexander Graham Bell's notebook. Downloaded from http://upload.wikimedia.org/wikipedia/commons/0/0c/AGBell_Notebook.jpg

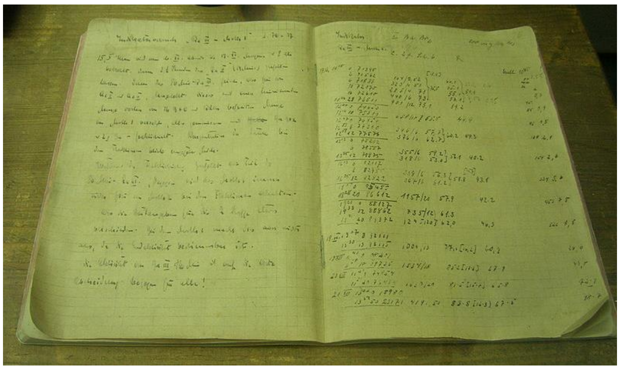

Figure 6: Otto Hahn's notebook. Picture downloaded from http://commons.wikimedia.org/wiki/File:Otto_Hahn%27s_notebook_1938_-_Deutsches_Museum_-_Munich.jpg

Portfolio

A portfolio is a collection of several pieces of work. Obviously, these pieces of work could be selected according to different criteria: A "performance portfolio" (Wiliam, 2011) or "product portfolio" (Bräuer, 1998) will display the latest and best pieces of work which supports summative assessment but does not say anything about the student's learning journey. In a "learning portfolio" (Wiliam, 2011) or "process portfolio" (Bräuer, 1998), on the other hand, a new, better piece of work does not replace an earlier one but is simply added in order to show the learning trajectory. This second type, the learning portfolios, obviously make sense when all the pieces of work collected belong to the some topic or are in some way comparable.

The learning portfolio or process portfolio might easily be combined with a reflection where the student analysis his / her progress him/herself.

5.2 Performance-based data about student learning (non - exhaustive list)

This chapter will introduce different means of performance - based data collection about student learning. The chapter is based on Bernholt et al., 2013).

Observation of performance / video

Direct observation of students' performance can be conducted by both peers or by the teacher. Suitable situations include the conduction phase of experiments, investigations, or construction tasks. It might often make sense to work with a list of criteria when observing students.

Student protocol

Student protocols are typically written into pre-structured files. Students note what they are doing (e.g. how they vary variables in an experiment or how they try out different solving approaches). It should be noted here that students often do not distinguish between their plans and their actual performance (Kemper & Tatzki, 2010).

Artefacts (constructed device, …)

Artefacts typically refer to Technology education and include all resulting objects from construction processes such as constructed devices, constructed machines, and constructed tools.

5.3 Oral data about student learning (non - exhaustive list)

This chapter will introduce different means of oral data collection about student learning. The chapter is based on Bernholt et al., 2013).

Oral presentation

Oral presentations refer to students' talks which are given to the whole class or to a smaller group of students. Typical topics in the context of inquiry include a specific solving approach or an experimental design and the corresponding results.

Debate (Iordanou, 2010)

This paragraph was written by Demetris Koursaris, Elena Siakidou, Nikos Papadouris, Costas Constantinou.

a) Preparation for the showdown. All students are divided into two groups (group A and group B) of equal number of members, depending on the position they are asked to defend (for example climate change is manmade or is due to natural processes). Half of the students in each of these large groups are asked to serve as specialists about the arguments in support of their own position (e.g. organize the evidence in support of their position). The "own argument" specialists are told that their task is to become familiar with the possible counterarguments the opposition might assert and to prepare rebuttals to use in the showdown. The team creates a set of "own argument – counter – rebuttal" sequences that are recorded onto color-coded cards, distinguishing each part of the argument sequence. The remaining half of the students is asked to serve as experts about the arguments in support of the other position (e.g. identify weaknesses in possible arguments for the other position). Members of the other team are the "other argument" specialists. Their task is to review effective counterarguments to use when faced with opponents' arguments. The cards produced by this team reflect the argument sequence of "other argument - counter". Each preparation team has an adult coach to facilitate the group process.
b) Showdown. The members of group A engage in argumentation, in a structured manner, with the members of group B. During the first half of the showdown, group A starts the debate. At half-time, group B continues the debate. The showdown has approximately 40 minutes duration.

Discourse, role - play

Discourse (from Latin discursus, meaning "running to and from") denotes spoken communications. In the context of science, technology and mathematics educations, this will usually signify a discussion about a subject issue.

Role-plays also refer to discussions about a subject issue with different opinions and views being brought up. In a role-play, the discussants do not defend their own opinion but an opinion that is attributed to the role they are playing. This typically facilitates discussions in class since students do not have to expose themselves and their own views. With predefined roles, is also easier to make sure that different views and opinions occur.

Assessment dialogue

An assessment dialogue (Christensen, 2004) involves both data collection about student learning and feedback. The procedure is described in chapter 6.4.

Interview, accountable talk

Interviews and accountable talks are similar to oral exams - except for the fact that they are not necessarily used for summative assessment. So an interview or an accountable talk involves questions from the teacher and answers from the student.

Audio tapes / video tapes

Audio tapes and video tapes are very frequently used in research but not so much in teaching practice. This has to do with the fact that going through long tapes is time-consuming for the teacher. However, in the context of inquiry, one option might be to ask students to record a tape of just a few minutes where they explain what investigation / solving approach / construction strategy they plan to follow and why. That way, listening to these tapes should not take the teacher / peers more time than reading the students' notebooks or reports.

5.4 Electronically collected data about student learning

This section was written by Steve Addison and Maia Dimitrova

The methods that are proposed facilitate a technology enhanced formative assessment (TEFA) strategy, which supports teachers' classroom practices and the transition to using novel forms of assessing IBE in STM using technologies, which may include social media and mobile apps, log files and learner interaction sequences, audio and video submissions, along with “traditional” written data collection. In this sense we suggest that technology can be used to support IBE in STM in the classroom to show or demonstrate concepts, particularly focused at the student as an active learner.

Wiliam, D., & Thompson, M. (2007) propose the following categories of feedback in formative assessment.

	Feed up	Feed back	Feed forward
	Where the learner is going	Where the learner is	How to get there
Teacher	Clarify and share learning intentions	Engineering effective discussions, tasks and activities that elicit evidence of learning	Providing feedback that moves learners forward
Peer	Understand and share learning intentions	Activating learners as learning resources for one another	
Learner	Understand learning intentions	Activating learners as owners of their own learning	

Figure 7: Strategies for formative assessment, Taken from Wiliam & Thompson, 2007.

Feedback is a key element of formative assessment: The use of computer based platform data obtained from ongoing class interactions will provide “additional information on skills such as time management, perseverance, and teamwork allowing feedback to be presented in many interesting and useful forms” (DiCerbo & Behrens 2014). The data produced by a student, or a group of students, will be available electronically to the teacher, peer and learner, as will the metadata attached to those data, providing many channels for rich feedback. A synthesis of these electronic data and metadata then increases the availability of information on which to understand the learning processes undertaken by the learner(s) and enhance the forms of feedback given.

6. Feedback methods selected for the ASSIST-ME project

A feedback method is a way of (1) diagnosing the student's level of achievement related to criteria and (2) to give feedback and to start a dialogue with the student(s) in regard of his / her learning progress and of the next steps in learning to be taken. This interaction could take place between the teacher and the student(s) or between peers. The concrete use of the different feedback methods is illustrated by paradigmatic examples.

The following paragraphs will introduce four feedback methods. For each of those, the basic principle will be described followed by small varieties. The four feedback methods include:

1) **Interactions on-the-fly** which describes informal formative assessment of individual students or small groups of students. On-the-fly assessment cannot be planned beforehand but takes place spontaneously when the teacher recognises good opportunities.
2) **Marking (grading and written comments)** which describes assessment and feedback on - often written - pieces of student work. Contrary to the aforementioned method, marking does not take place spontaneously but in planned situations.
3) **Self- and peer-feedback** describe reflections on the students' own learning as well as assessment which is provided by peer students. In both varieties, it is most important that the students clearly understand the criteria of success.
4) **Open classroom discussion and structured classroom dialogue** summarizes different varieties of oral assessment.

These four feedback methods reflect the diversity of formative assessment. However, there is one common aim for all the procedures: *"Feedback should cause thinking"* (Wiliam, 2011).

6.1 Interactions on-the-fly

The feedback method "interactions on-the-fly" describes informal formative feedback. This chapter will provide a description of the principle along with short summaries of different varieties.

Principle of interactions on-the-fly

"On-the-fly formative assessment arises when a "teachable moment" unexpectedly occurs, for example, when a teacher circulating and listening to the conversation among students in small groups overhears a students say that, as a consequence of her or his experiment, 'density is a property of the plastic block and I doesn't matter what the mass or volume is because the density stays the same for that kind of plastic.' The teacher recognizes the student's grasp of density and challenges the student with other materials to see if she or he and her or his group-mates can generalize the density idea." Shavelson et al., 2008, p.300.

Complementary to 'on-the-fly formative assessment' is 'planned-for-interaction formative assessment'. Planned-for-interaction formative assessment includes marking (see chapter 6.2); peer- and self-assessment (see chapter 6.3); open classroom discussion and structured classroom dialogue (see chapter 6.4).

Varieties (non-exhaustive list)

Assessment conversation (Duschl, 2003; Duschl & Gitomer, 1997; Ruiz-Primo & Furtak, 2006)

Ruiz-Primo & Furtak, 2004, Ruiz-Primo and Furtak, 2006a, and Ruiz-Primo and Furtak, 2006b, describe typical assessment conversations as a four-step cycle, where the teacher elicits a question, the student responds, the teacher recognizes the student's response, and then uses the information collected to student learning (see figure 3). 'Eliciting' means evoking, educing, bringing out, or developing. To describe a teacher’s actions as eliciting during informal formative assessment is thus an accurate description, as teachers are calling for a reaction, clarification, elaboration, or explanation from students. Typical examples of such eliciting questions include "Why do you think so?" or "What does that mean?" (Ruiz-Primo & Furtak, 2006b). During informal formative assessment, teachers must react on the fly by recognizing whether a student’s response is a scientifically accepted idea and then use the information from the response in a way that the general flow of the classroom narrative is not interrupted (e.g., calling students in the class to start a discussion, shaping students’ ideas).

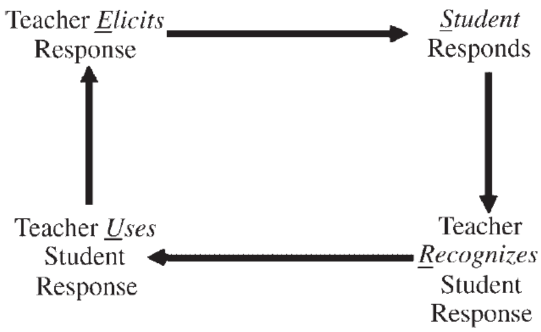

Figure 8: The ESRU model of informal formative assessment (taken from Ruiz-Primo and Furtak, 2006.

The following table displays typical teacher's strategies for the different dimensions of the ESRU cycle.

Eliciting	Recognizing	Using
Epistemic frameworks		
Teacher asks students to:	Teacher:	Teacher:
• Compare/contrast observations, data, or procedures	• Clarifies/Elaborates based on students' responses	• Promotes students' thinking by asking them to elaborate their responses (why, how)
• Use and apply known procedures	• Takes votes to acknowledge different students' ideas	• Compares/contrasts students' responses to acknowledges and discuss alternative explanations conceptions
• Make predictions/provide hypotheses	• Repeats/paraphrases students words	• Promotes debating and discussion among students' ideas/conceptions
• Interpret information, data, patterns	• Revoices students' words (incorporates students' contributions into the class conversation, summarizes what student said, acknowledge student contribution)	• Helps students to achieve consensus
• Provide evidence and examples	• Captures/displays students' responses/explanations	• Helps relate evidence to explanations
• Relate evidence and explanations		• Provides descriptive or helpful feedback
• Formulate scientific explanations		• Promotes making sense
• Evaluate quality of evidence		• Promotes exploration of students' own ideas
• Suggest hypothetical procedures or experimental plans		• Refers explicitly to the nature of science
• Compare/contrast others' ideas		• Makes connections to previous learning
• Check students' comprehension		
Conceptual structures		
Teacher asks students to:		
• Provide potential or actual definitions		
• Apply, relate, compare, contrast concepts		
• Compare/contrasts others' definitions or ideas		
• Check their comprehension		

Table 1: Typical teacher's strategies for the different dimensions of the ESRU cycle. Taken from Ruiz-Primo and Furtak, 2006.

6.2 Marking (grading and written comments)

The feedback method "marking (grading and written comments)" describes formative feedback in a written form, typically based on written student work such as reports, written answers, etc. This chapter will provide a description of the principle along with short summaries of different varieties.

Research shows that grading and written comments should not be combined in the same piece of work since students will only focus on the grading and not devote themselves to the written comments.

Principle of grading

Grading and rating is formatively valuable as soon as students know which aspects of learning the grading refers to (Smit & Birri, 2014). So if the grading is connected to different criteria (for example in a scoring rubric), students get an idea of where to improve.

The advantage for students is that they get a broad overview of their level of achievement due to the different criteria. For teachers, grading is a fast way of providing feedback to students and to get an overview of their learning which might help for planning the subsequent lessons.

Varieties of grading (non-exhaustive list)

Scoring rubrics (Burke, 2006; Arter & McTighe, 2001; Moskal, 2003; Smit & Birri, 2014)

Rubrics articulate the expectations for an assignment or a learning goal by listing the relevant criteria the teacher looks for, or what counts that students should show to demonstrate various levels of performance. The teacher indicates the student's scoring by placing a cross in the correct level of performance.

Rating

The rating system which is integrated in the inquiry platform (described in chapter 7) is another variety of grading: teachers or peers rate a student's work and by comparing the different ratings over time, the improvement of the student becomes visible.

Principle of written comments

Written comments should identify what has been done well and what still needs improvement, and give guidance on how to make that improvement (Black et al., 2003). The same authors explain that simple 'good', 'well done', … is not sufficient since these general evaluations do not say what has been achieved nor what should be the next steps to be taken.

Written comments have the advantage that they allow the assessor to concentrate on specific problems and specific strengths of a piece of work. This is especially valuable for weak students (Black & Harrison, 2004). On the other hand, written comments which are useful for the learners need some time to be written. The same authors, Black & Harrison, 2004, advise teachers / assessors to

- Write comments that initiate learning immediately (example of such a comment: "Can you suggest how the plant might disperse its seeds?"; (Black & Harrison, 2004))

- Write comments that relate back to the success criteria of descriptions of quality (Black & Harrison, 2004)
- Mention the target in the comments (example of such a comment: "Think about the accuracy and neatness when drawing graphs" (Black & Harrison, 2004))
- Include advice where the students should go for help and what to do to improve.

However, Black et al., 2004, also mention that only tasks that are useful in revealing students' understandings and misunderstandings provide the opportunity to write useful comments. The same authors also write that the students should be given the opportunity to respond to comments.

Varieties of written comments (non-exhaustive list)

Sheet attached to the learner's book (Black & Harrison, 2004)

The top of an A4 sheet of paper is attached into the back cover of the learner's book where both the teacher and the learner write their comments. This should allow for a dialogue between student and teacher.

'Two stars and a wish' (Black & Harrison, 2004)

In order to cover both strengths and weaknesses of a written piece of work, comments should be provided in the form of two stars (two strengths) and a wish (a weakness that needs improvement).

6.3 Self- and peer- feedback

The feedback method "self- and peer-assessment" describes formative assessment which is conducted by the learner him/herself or by student peers. This chapter will provide a description of the principle along with short summaries of different varieties.

In both self-and peer-feedback, it is of central importance that the goal of a task and the criteria of evaluation are understood well by the students (Sadler, 1989; Black et al., 2003). Black et al. (2003) suggest supporting this understanding by showing examples.

Both self-and peer-feedback allow the teacher to freely move between the students and concentrate on individual problems since she / he does not carry the responsibility to do all the assessment of the whole class.

The process of peer- and self-assessing pieces of work from time to time should help the students to bear in mind the aims of their work and therefore assist them in becoming independent learners (Black et al., 2003).

Principle of self - asssessment

Self-assessment means that each student reflects on the quality of his / her own work, or on his / her understanding of a topic that is just being discussed, or on his / her performance, or similar.

Varieties of self-assessment (non-exhaustive list)

Self-assessment rubrics (Burke, 2006; Arter & McTighe, 2001; Moskal, 2003; Smit & Birri, 2014)

The system is exactly the same as with scoring rubrics: again, the rubric consists of a list of relevant criteria indicating what counts that students should show to demonstrate various levels of performance. However, this time, it is not the teacher who decides on the level of performance but the student who assesses himself / herself.

Traffic lights (Black & Harrison, 2004)

Traffic lights are a very fast way for the students to show if they understand what is being talked about: Each student has a green, a yellow, and a red card. The colours symbolize good, partial or little understanding of what the teacher is talking about. So if many students are showing the green card, the teacher knows she/he can carry on. A lot of red cards tell the teacher that the work needs to be revisited for the students to gain a better understanding. A similar colour code also works, for example, when students give very short talks on specific topic to their peers - and the peers judge the talk green (better than what the listening peer could have done), yellow (about the same quality as the listening peer could have done), or red (some parts missing or incorrect).

Principle of peer - feedback

Peer-feedback follows the idea of "activating students as instructional resources for one another" (Leahy et al., 2005). Peer-feedback is seen as particularly powerful since *"students may accept criticisms of their work from one another that they would not take seriously if the remarks were offered by a teacher. Peer work is also valuable because the interchange will* *be in language that students themselves naturally use […]"* (Black et al., 2004, p. 14). The same authors find evidence that *"when students do not understand an explanation, they are likely to interrupt a fellow student when they would not interrupt a teacher." (Black et al., 2004, p. 14).*

However, Black et al., 2003, also mention that before being able to assess their peers' work, they have to learn how to behave in groups (listening to others, taking turns) and how to communicate their feedback usefully.

Varieties of peer - feedback (non-exhaustive list)

Reciprocal peer-feedback

Reciprocal (or two-way) peer-feedback is the type of feedback which emerges when students get involved with a reciprocal peer-assessment setting. In r*eciprocal* peer-assessment, students undertake both the role of the assessor and the assessee, by assessing each other's work. The rationale lying behind reciprocal peer-assessment is that all the students are given the opportunity to experience both the role of the assessor and the assessee and benefit from both practices. In order to implement reciprocal peer-assessment there is a need to compose pairs of individual students or pairs of students' groups. Then the pairs of students and/or groups exchange their work/ learning outcomes which have resulted during the learning process. Initially in the peer-assessor role, the students are asked to assess their peers' work and to produce peer feedback. The peer feedback could be either of quantitative nature (e.g. grades) and/ or qualitative (e.g. oral or written comments which could include suggestions and recommendations for future action). The aim of the qualitative peer feedback is to assist peers in identifying the strengths and weakness or their work and in addition to provide suggestions for improving their learning process (Topping, 2003). Performing the peer-assessor role requires from students to have and practice their assessment skills, namely: *defining criteria, judging the performance of a peer, and providing feedback* (Sluijsmans, 2002). Students could be supported through the provision of scaffolds while performing each one of these assessment skills. For example, if students are novices in peer-assessing and have no prior experience on how to define assessing criteria or what has to be measured in the learning process and thus compose assessment criteria, they could alternatively be provided with those criteria from the teacher, in order to better execute their task. In that case, usually criteria are provided to peer assessors in the form of a rubric (see, for instance, Hafner & Hafner, 2003; Kocakülah, 2010). If the students have already acquired some expertise on peer-assessment, then they could define by themselves which elements of the task determine how success of the performance is measured (Topping, 2003) and therefore compose their own assessment criteria in regard to this. Concerning to the skill of *judging the performance of a peer*, students are responsible to critically analyze and judge a peer's performance, by applying the assessment criteria that have been given by the teacher (Topping, Smith, Swanson, & Elliot, 2000), or the assessment criteria that have been defined by themselves. With regard to the skill of *providing feedback*, peer assessors need to communicate their judgments to peer assessees and provide constructive feedback about their learning process. After having completed their task as peer-assessors, students change roles and become the assessees. Students receive the peer-feedback initially created by their peers. In the peer-assessee role, students are called to critically review the peer feedback received and decide on the actions to be taken. The skills required for enacting this role are different in nature from those of the peer-assessor. Peer-feedback might include flaws, since peer assessors are most probably novices in giving feedback. Therefore peer assessees need to filter the peer feedback and then decide whether there is a need to adopt peers' suggestions and recommendations and therefore whether there is a need to revise their work and/or making considerations in their future work.

In reciprocal peer-assessment students could potentially benefit from experiencing both roles. Firstly in the peer-assessor role, the students practice and develop the aforementioned assessment skills (Hanrahan & Isaacs, 2001; Lin, Liu, & Yuan, 2001; Topping, 1998). Second, when writing feedback, students have more opportunities to engage in important cognitive activities, such as critical thinking (e.g., deciding what constitutes a good or poor piece of work), reflection etc. Third, students' informational resources expand by viewing and reviewing peers' work since they are given the opportunity to see examples of other students' work. This could potentially lead to experiencing implicitly self-assessment too, by comparing their own work and that of their peers', hence reflecting on their own learning achievements.

A number of benefits for learning could also be associated with the peer-assessee role (Tsivitanidou, Zacharia, & Hovardas, 2011; Hanrahan & Isaacs, 2001; Harlen, 2007; Lin et al., 2001; Lindsay & Clarke, 2001; Topping, 2003). Firstly, students get the opportunity to receive additional feedback, compared to a more traditional setting where feedback usually comes from the teacher. Secondly, peer feedback might be more comprehensible to students since they share a common language/ coding. Thirdly, feedback derives from peers who have experienced the same learning process and possibly who have faced the same difficulties while performing the tasks of the learning sequence. As a result, the peer feedback could detect in a more direct way possible ways to overcome those difficulties and in a comprehensible language. Finally students, while enacting the peer assessee role, engage in important cognitive activities, such as critical thinking (e.g. while filtering peer feedback and deciding what constitutes a good or not peer feedback).

One-way peer-feedback

One-way peer-feedback is the type of feedback which emerges when students get involved with a one-way peer-assessment setting. In one-way peer-assessment, students undertake either the role of the assessor or the assessee. The different element of one-way peer-assessment from that of reciprocal peer-assessment is that in the first method the students can either only provide peer feedback or merely receive peer feedback. For example in that case a group of students could act as the assessors and a group of students could act as the assessees. This type of peer-assessment method falls short of the benefits that could emerge when a student experiences both the role of the assessor and the assessee.

6.4 Open classroom discussions and structured classroom dialogues

The feedback method "open classroom discussions and structured classroom dialogues" describes formative feedback which is conducted based on oral activities. This chapter will provide a description of the principle along with short summaries of different varieties.

Both open and structured classrooms discussions need authentic questions or issues as a starting point (Stewart et al., 1995; Christensen, 2004; Black et al., 2003). Students are asked to express their ideas and opinions on that issue, this serves as a basis for the assessment of their understanding. Black & Harrison, 2004, explicitly mention that it is not trivial to frame good questions that have the potential of stimulating classroom discussions. They therefore advise the teachers to carefully design the topic of discussion.

As students should express their ideas and thoughts, it is important to have a "supportive climate" in the classroom where all students are aware of and follow the rules of communication (Stewart et al., 1995; Christensen, 2004; Black et al., 2004).

Principle of open classroom discussions (Black et al., 2003; Black et al, 2004; Black & Harrison, 2004)

Open classroom discussions start with a question that provokes thoughtful answers (for example: "Some people describe friction as the opposite of slipperiness. What do you think?" (Black et al, 2003)). One might also start with a sample answer on an open question, or with an answer pattern of a multiple choice question. Black et al., 2003 then make the point that it is extremely important to wait for the students to think about a good answer or even discuss it in pairs instead of immediately responding in class. The teacher should then promote the discussion and develop student reflection by "effective questions" (Black & Harrison, 2004) such as

- Why …?
- What is the difference between experiment "a" and experiment "b"?
- What is similar and what is different about …?
- What can you prove by … ?
- What can we add to x's answer?
- Which parts of x's answer would you agree with?
- Where else might we find x's idea working?
- Would x's method work in all cases?
- Are x's and y's ideas same or different?

The teacher should focus on what students say rather than just accepting an answer and moving on - this creates an enhanced opportunity for sustained discussion.

Principle of structured dialogues

This paragraph was written by Demetris Koursaris, Elena Siakidou, Nikos Papadouris, Costas Constantinou.

A structured dialogue is a disciplined form of dialogue, where participants agree to follow a framework or facilitation, enables groups to address complex problems shared in common (Christensen, 2004).

Features that characterized structured dialogue (Stewart et al., 1995; Christensen, 2004)

- Authentic questions or issues that encourage the dialogue (e.g. socio-scientific issues, topics that hits the zone of uncertain knowledge)
- Specific rules that formulate the context of the dialogue process
- Students must be aware of these rules
- Students undertake and alternate roles, to ensure that during the dialogue, even the silent students will be active listeners
- Students are given the freedom express their ideas
- Feedback among students

Advantages using structured dialogue

- Provides teachers with easy access to data (e.g. students views, feedback between peers) that may be collected formally (e.g. observation protocol)
- Provides students with easy access to data (e.g. listening and participating the dialogue) that may be collected formally (e.g. rubrics, taking notes)
- Feedback opportunities
- Students take ownership of their own learning
- A higher level thinking is achieved through respectful interaction

Varieties of structured dialogues (non-exhaustive list)

Socratic Seminar (Adler, 1982; Polite & Adams, 1997; Pihlgren, 2007)

This paragraph was written by Demetris Koursaris, Elena Siakidou, Nikos Papadouris, Costas Constantinou.

The Socratic Seminar is a formal discussion, based on an authentic text or a question that are provided by the teacher. However the teacher is the facilitator, not the leader, providing scaffolding only where needed. Within the context of the discussion, students listen closely to the comments of others, think critically for themselves and articulate their own thoughts or views and their responses to the thoughts of views of others. Consequently, the seminar is a collaborative, open-ended dialogue spurred by questions that encourage critical thinking, deep understanding of the discussed topic and active listening skills. In this type of structured dialogue, instead of debate, the participants carry out the burden of responsibility for the quality of discussion.

The basic rules of the Socratic Seminar, that students must be aware are: a) not to raise hands, b) listen carefully, c) address one another respectfully. Firstly, the students sit in an inner and an outer circle. Only the inner circle may speak and they must speak respectfully to one another. In this phase of the Socratic Seminar, students need to build off what each other says (e.g. “Your comment leads me to think about…”, “Can you clarify what you meant by…”). Furthermore, speakers need to use a strong voice, maintain eye contact and allow students to finish their thoughts. This procedure is occurred with no hand rising. An important point, is that students must justify their opinion providing evidence or by indicating a specific part of the text that supports of what they are saying. The outer circle needs to observe actively the discussion occurred in the inner circle by taking notes, in order to provide feedback in specific points to their peers (inner circle). Also, students must change roles (the inner circle becomes the outer circle and conversely). Finally, students discuss in pairs of what they have learned.

Teacher-Student Assessment Dialogue (Christensen, 2004)

The Teacher-Student Assessment Dialogue consists of two separate but connected dialogues. The first is a dialogue between one student and the teacher (around 5 minutes) with the rest of the class grouped in a close social circle around and with one task only, namely to listen. The second dialogue is a prolonged dialogue where everybody can join in. It has no time limit and takes place in the social circle in the immediate aftermath to the first dialogue. Typically these prolonged dialogues last 5 to 10 minutes. They deal with the subject from the first dialogue and they often have a reflective character. Depending on the motivation and attention of the students, the formality of the arrangement may vary.

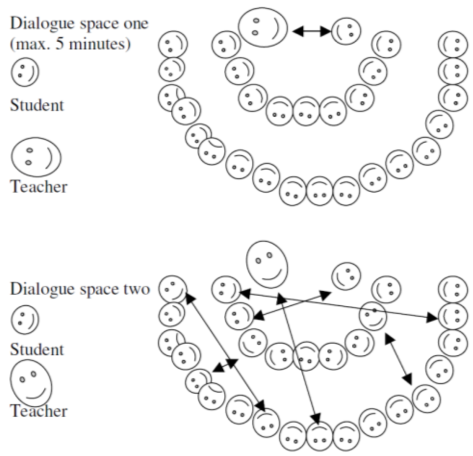

Figure 9: Teacher-Student Assessment Dialogue. Taken from Christensen, 2004.

The 'news' compared to ordinary teacher-student dialogues lies in the insistence on a 5 minute dialogue between one student and the teacher in the (semi)public classroom. It is a long time for a student to try to match the teacher (an expert) in a dialogue. In an ordinary class dialogue the students take turns in the dialogue. If one does not know the answer another might. An argument one student cannot carry through may be completed by another etc.

The most significant element in the development of the idea of the Teacher-Student Assessment Dialogue is the emergence of a new dialogue separate but connected to the Teacher-Student Dialogue. The Teacher-Student Dialogue (dialogue space one) is characterized by its formal and strict rules including a time limit and the fact that the student is placed face to face with the teacher before the rest of the class. Dialogue space two is characterized by a narrow link to dialogue space one subject-wise and time-wise. But in contrast to the rules in dialogue space one everybody can speak in dialogue two and there is no time limit other than what the teacher judge to be appropriate.

7. The ASSIST-ME inquiry platform

This chapter was written by Maia Dimitrova, Steve Addison, Terry Eagling Joyce.

Following discussions and feedback from project partners it has been decided that the project would develop an online inquiry platform to support inquiry-based teaching, learning and assessment in science, mathematics & technology. This is considered to be more appropriate for this project and replaces the onscreen assessment methods presented in deliverable D4.3 part 2. The platform will have two main parts – a teacher and a student one.

Different versions of the student platform may be developed depending on the requirements identified by each of the following subjects and levels: Secondary science; secondary mathematics; and secondary technology. The user interface will differ between the primary and secondary versions for each subject, as well as some of the data creation and manipulation mechanisms available. The same secondary versions will be available to lower and upper secondary schools.

Figure 10 introduces the main components of the two main parts that comprise the ASSI ST-ME inquiry platform: teacher and student. The boxes represent each component and the curved arrows indicate that students can view the inquiries and recourses created by their teachers and teachers can view and comment on all the work created by their students.

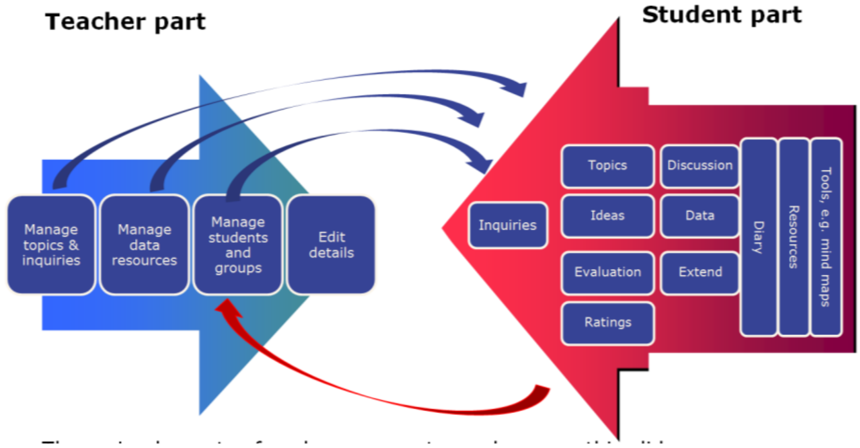

Figure 10: Main structure of the ASSIST-ME inquiry platform.

The following two tables give an overview of what steps the students at either secondary or primary level could take when investigating and how peers and the teacher can see and comment on the students' work. These steps are aligned with the main elements of the competence frameworks described in the next chapter.

Means of interaction for formative assessment in the ASSIST-ME inquiry platform at secondary level
Discussions about the topic Students formulate ideas and discuss them with each other. Teachers use the noticeboard to pose questions or share their feedback with students.
Discussion the investigations

Students further discuss the steps they will undertake, changes they would like to make. Teachers are able to see the ideas of all the study groups in their class. After the class teachers can review the ideas from all the groups and comment on them ensuring every student and every group receives feedback.
Idea definition Once the ideas have been discussed and refined, students will be able to describe them in more detail. Students give their idea a name and write a short description. At this stage students start thinking of inquiry questions, discuss them with their peers and refine them in or outside the classroom. Hints are available for students needing help. Teachers will be able to see how students have defined their inquiries and comment on them.
Planning the investigation Once students are happy with their idea and questions, they start planning their investigations. This could include any steps they are planning to undertake. Hints will be available for students needing help with planning their inquiry. Teachers will be able to see and comment on students' plans .
Defining variables As part of their investigation plan, students may choose to specify the variables they would like to measure. Hints will be available for students needing help with defining variables.
Planning resources Students also specify the type of data they want to collect as part of their inquiry or investigation.
Uploading data & other evidence Students upload all the data they have gathered and describe it. They specify the question or hypothesis that the data best supports. They re-order each resource using the arrows, share it with their teacher or delete the resource. Each resource will have the user id of the student that has uploaded it. Hints will be available for students needing help. Teachers will be able to see and comment on all the evidence gathered by students.
Manipulating data & other evidence A set of mechanisms will be available should students want to amend the resources they have uploaded. Students use these tools to create a variety of charts and graphs using data they have already uploaded.
Data analysis Once most data has been gathered during the investigation, students review it and explain their findings. They see all the data uploaded for this investigation. Students drag and drop resources in the analysis description if they would like to include them. Teachers will be able to see how students have analysed their data and comment on their analysis.
Evaluating findings Students reflect on their findings, record their thoughts and their conclusions. Teachers will be able to review and comment on students' evaluations.
Providing conclusions Students provide their final reflections and evaluations over the course of the inquiry. At the bottom of the screen they provide ratings about how they have performed on the inquiry. Teachers will be able to review and comment on students' conclusions.
Progress rating At the end of each stage, students rate their progress during each stage of the investigation. Teachers will be able to rate students' progress as well, which students will be able to see at the bottom of the screen together with their group rating.
Metacognitive reflection Using the diary function, students can reflect on and record all their steps in and outside of the classroom.
Usage statistics and progress feedback Students and teachers will be able to view

Table 2: Means of interaction in the ASSIST-ME inquiry platform at secondary level.

Means of interaction for formative assessment in the ASSIST-ME inquiry platform at primary level
Discussion board Students will be able to discuss with each other topics provided by the teacher or an element of an inquiry, e.g. hypotheses, a plan or assets that they have uploaded.
Idea definition Students will be able to provide simple descriptions of their ideas. They will be able to either type their ideas or upload an audio or video recording. Hints will be available from a helpful cartoon character. Teachers will be able to see how students have defined their inquiries and comment on them.
Planning the investigation Once students are happy with their idea and questions, they can provide simple steps for their investigations. They will be able to either type their suggestions or upload an audio or video recording. Hints will be available from a helpful cartoon character. Teachers will be able to see and comment on students' plans .
Defining variables As part of their investigation plan, students may choose to specify a small number of variables they would like to measure. Hints will be available from a helpful cartoon character.
Uploading data & other evidence Students upload all the data they have gathered and describe it. They specify the question or hypothesis that the data best supports. They re-order each resource using the arrows, share it with their teacher or delete the resource. Each resource will have the user id of the student that has uploaded it. Hints will be available from a helpful cartoon character. Teachers will be able to see and comment on all the evidence gathered by students.
Data analysis Once most data has been gathered during the investigation, students review it and explain their findings. They see all the data uploaded for this investigation. Students drag and drop resources in the analysis description if they would like to include them. Hints will be available from a helpful cartoon character. Teachers will be able to see how students have analysed their data and comment on their analysis.
Providing conclusions and next steps Students provide their final reflections and evaluations over the course of the inquiry. Student will also be able to record their next steps. They will be able to either type their ideas or upload an audio or video recording. Hints will be available from a helpful cartoon character. Teachers will be able to review and comment on students' conclusions and proposed next steps.
Progress rating At the end of each stage, students can rate their progress during each stage of the investigation. Teachers will be able to rate students' progress as well, which students will be able to see at the bottom of the screen together with their group rating.
Progress feedback Simple progress bar will be visible at all times so that students can see how they are progressing through an inquiry.

Table 3: Means of interaction in the ASSIST-ME inquiry platform at primary level.

Additional functionality will be available to allow teachers and students to create study groups, start discussion topics and new inquiries, and add events to a diary or calendar.

A room metaphor has been used to ease students with navigating within the platform. Figure 11 depicts a screenshot of the main student page.

Figure 11: Student home page.

Figure 12 shows how one of the pages of the Ideas room within an inquiry will look.

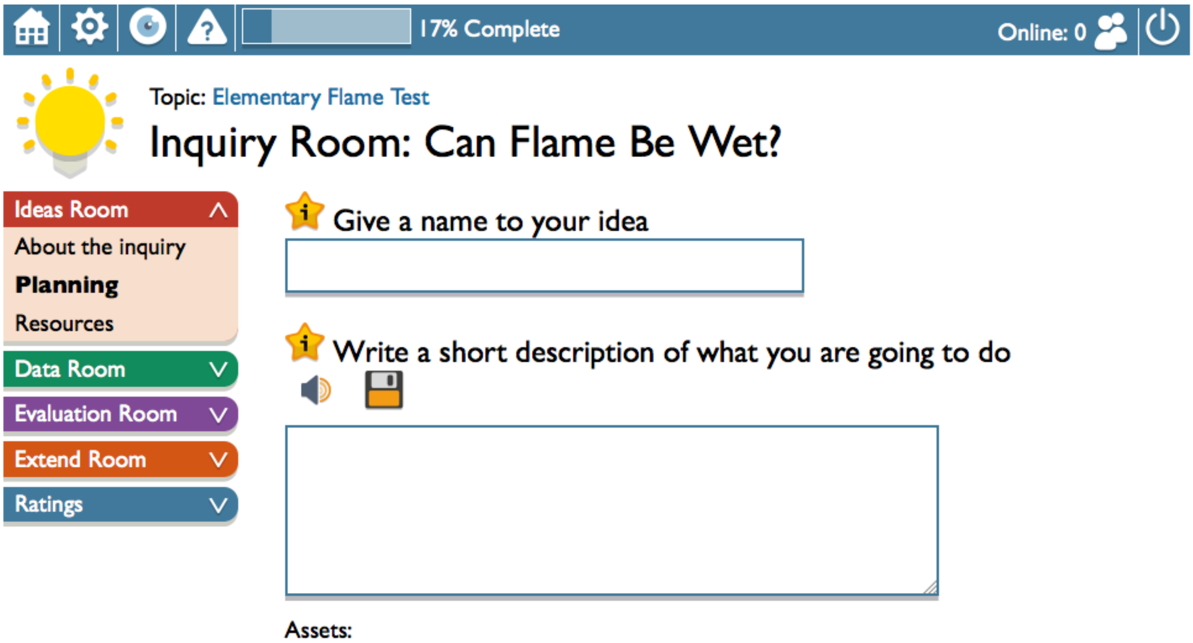

Figure 12: View of the Ideas Room within an inquiry.

As well as entering text, on most pages students will be able to upload an audio or a short video recording of themselves describing their ides or plans, etc.

The platform will be accessible from any computer or mobile device with an Internet connection. Users will be able to interact with the platform either by using a mouse or touch screen interface.

Finally, different language versions will be available so that students and teacher will be able to use the platform in their native language.

8. Competences selected for the ASSIST-ME project

8.1 Definition of 'competence'

The first paragraph of this section was taken from the proposal of the ASSIST-ME project (Dolin, 2012).

A competence is understood as a combination of skills, knowledge, characteristics, and traits that contribute to performances in particular domains. Hartig, Klieme and Leutner (2008) describe a competence as a complex ability that is closely related to performance in real life situations. With respect to science education, this definition is not far from what PI-SA describes as scientific literacy referring to an individual's scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues (OECD, 2006). Following this understanding of competence, Shavelson considers that: "a competence measure should tap complex physical and/or intellectual skills, produce observable performance on a common, standardized set of tasks with high fidelity to the performances observed in the "real world" ("criterion") situations to which inferences of competence are to be drawn, with scores reflecting the level of performance (mastery or continuous) on tasks where improvement can be made through deliberative practice" (Shavelson, 2011).
Inquiry-based education (IBE) can promote achievement of two different types of objectives: Objectives related to domain specific competences, i.e. key competences in mathematics, science and technology. Objectives related to transversal competences, i.e. cross curricular competences (we use the terms transversal competences and cross curricular competences synonymously). The line of separation between these two sets of competence goals is not sharp and even within each type of objective there might be considerable overlap.

Based on the model in Bernholt et al., 2013; Ropohl et al., 2013 and Rönnebeck et al., 2013, specific competences relevant in inquiry were selected for assessment in ASSIST-ME workpackage 4.

- **Investigation** (in science education)
- **Problem solving** (in Mathematics education)
- **Engineering design** (in Technology education)
- **Argumentation**
- **Modelling**
- **Innovation**

The competences are not completely separable but that is not considered as a major problem: teachers have a choice of different ways to assess their students' inquiry-based learning anyways. In order to draw the attention away from the sole "conducting experiments" towards other IBE-relevant competences and activities, it might even be good if there is a certain overlapping of competences assessed.

Each of the six competences will be further refined into sub-competences. The sub-competences with associated learning progressions can be found in chapters 8.2 - 8.7.

8.2 Investigations in science

Investigations in science involves four groups of subcompetences: The first group of subcompetences describes the ***preparation*** for an investigation. It involves identifying the question, searching for information, formulating hypotheses or making predictions.

The second group of subcompetences refers to the ***realization*** of an investigation. It involves planning and carrying out experiments, analyzing, interpreting and evaluating data and results.

The third group of subcompetences involves the ***evaluation*** of an investigation. This includes developing explanations, constructing and using models, engaging in argumentation from evidence.

The fourth sub-competence refers to the ability to ***communicate*** scientifically in different situations and at all steps of the inquiry process.

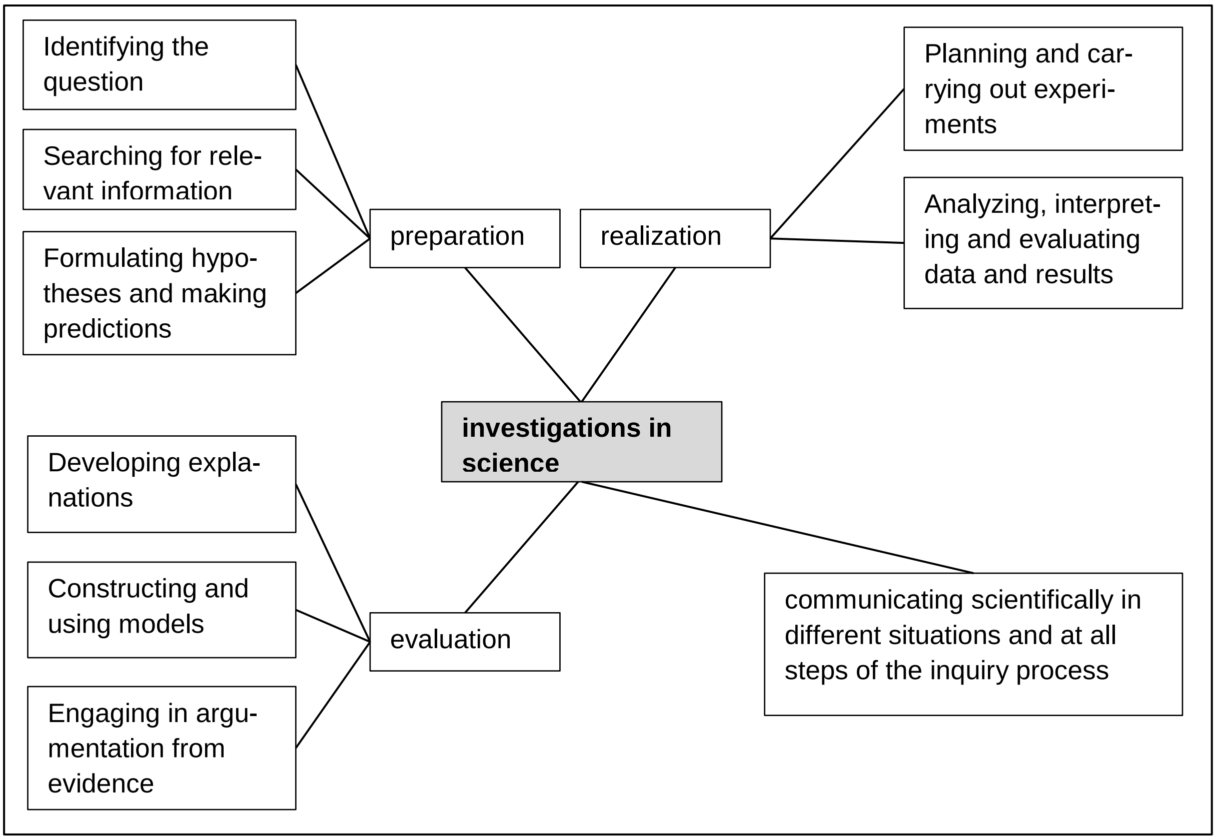

Figure 13: Investigation competence framework (based on Rönnebeck & Ropohl, 2014).

The following example of a learning progression for the sub-competence "identifying the question" is thought to serve as an example for the local working groups. The example is inspired by learning progressions developed in Switzerland (Beerenwinkel & Labudde, 2011), and by the Swiss educational standards in Mathematics and science (EDK, 2011). The national educational standards have been elaborated over a period of several years, are supported very broadly, and have been approved by the Swiss Conference of Cantonal Ministers of Education (EDK).

Local working groups who develop their own learning progressions should keep in mind that students' levels of competence may not evolve linearly or step - by - step as it may look like in the example here. More exemplary learning progressions for 'investigations in science' can be found in the appendix.

Sub-competences	**Exemplary basic standards for grade 4 science students**	**Exemplary basic standards for grade 6 science students**	**Exemplary basic standard for grade 9 science students**	**Exemplary basic standard for grade 12 science students**
Identify the question	Guided by the teacher, students are able to perceive, observe, and describe simple situations and phenomena with several senses. They can raise simple questions based on the aforementioned actions.	Students are able to perceive, observe, and describe simple situations and phenomena with several senses. They can raise questions based on the aforementioned actions.	Students are able to perceive, observe, and describe *situations and phenomena* with several senses. They can *formulate diversified questions* based on the aforementioned actions.	Students are able to perceive situations and phenomena with several senses, observe them *precisely,* and describe them *using adequate terminology*. They can formulate diversified questions based on the aforementioned actions.

Table 4: Exemplary learning progressions for investigation competence in science education (based on EDK, 2011; Beerenwinkel & Labudde, 2011)

8.3 Problem solving in mathematics

Problem solving in mathematics education involves four groups of subcompetences: The first group of sub-competences describes the ***preparation*** for problem solving. It involves describing and understanding mathematical or ‚real world' problems, transferring problems into the ‚mathematical world' (if necessary), exploring problems and making conjectures, identifying what is known and what is unknown.

The second group of subcompetences refers to the ***realization*** of problem solving. It involves creating, using and manipulating mathematical representations, planning and carrying out a problem solving strategy.

The third group of subcompetences involves the ***evaluation*** of problem solving. This includes making and analyzing connections, evaluating the strategy, the conjectures and the meaningfulness of the results, generalizing and systematizing the results and the specific problem solving strategy.

The fourth subcompetence is ***communicating*** one's actions by using adequate vocabulary/representations at every stage of the process.

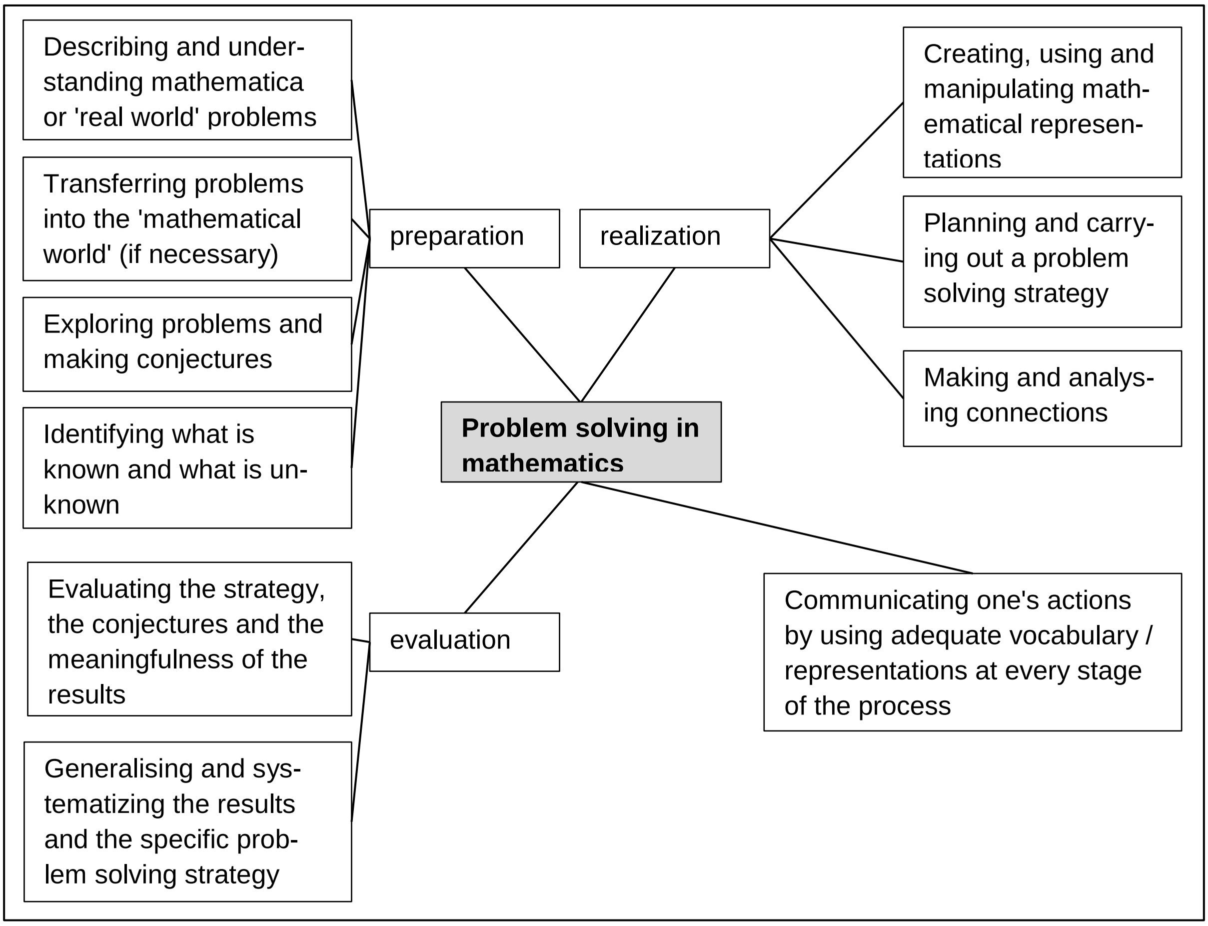

Figure 14: Problem solving competence framework (based on Rönnebeck & Ropohl, 2014).

The following example of a learning progression for the sub-competence "creating, using and manipulating mathematical representations" is thought to serve as an example for the local working groups. The example is inspired by learning progressions developed in Switzerland (Streit and Schick, 2011; Beerenwinkel & Labudde, 2011), and by the Swiss educational standards in mathematics and science (EDK, 2011). The national educational standards have been elaborated over a period of several years, are supported very broadly, and have been approved by the Swiss Conference of Cantonal Ministers of Education (EDK). The content of the learning progressions has been adapted from OECD, 2013.

Local working groups who develop their own learning progressions should keep in mind that students' levels of competence may not evolve linearly or step - by - step as it may look like in the example here. More exemplary learning progressions for problem solving in mathematics' can be found in the appendix.

Sub-competences	Exemplary basic standards for grade 4 mathematics students	Exemplary basic standards for grade 6 mathematics students	Exemplary basic standard for grade 9 mathematics students	Exemplary basic standard for grade 12 mathematics students
Creating, using and manipulating mathematical representations	Students are able to represent simple mathematical problems in a specified mathematical representation such as a table, a graph, a symbol.	Students are able to represent simple mathematical problems in a specified mathematical representation such as a table, a graph, a symbol.	Students are able to represent *mathematical problems containing relational propositions or assignment propositions* in a given mathematical representation such as a table, a graph, a symbol.	Students are able to represent mathematical problems containing relational propositions or assignment propositions in a *suitable* mathematical representation such as a table, a graph, a symbol.

Table 5: Exemplary learning progressions for problem solving competence in mathematics education (based on OECD, 2013; Muijs & Reynolds, 2011; EDK, 2011; OECD, 2013).

8.4 Engineering design in technology

Engineering design involves four groups of subcompetences. The first group of subcompetences describes the ***preparation*** for engineering design. It involves defining and delimiting a problem, need or desire, identifying constraints and criteria, investigating relevant information, generating and evaluating possible solutions, analyzing alternatives, selecting a potential solution, justifying the decision.

The second group of subcompetences refers to the ***realization*** of engineering design. It involves planning design of prototype, constructing prototype (using suitable tools/materials), testing prototype by collecting, analyzing, interpreting and representing data.

The third group of subcompetences involves the ***evaluation*** of engineering design. This includes evaluating prototype against the criteria, reasoning, modifying the design and redesigning if necessary.

The fourth subcompetence is ***communicating*** at all stages of the process.

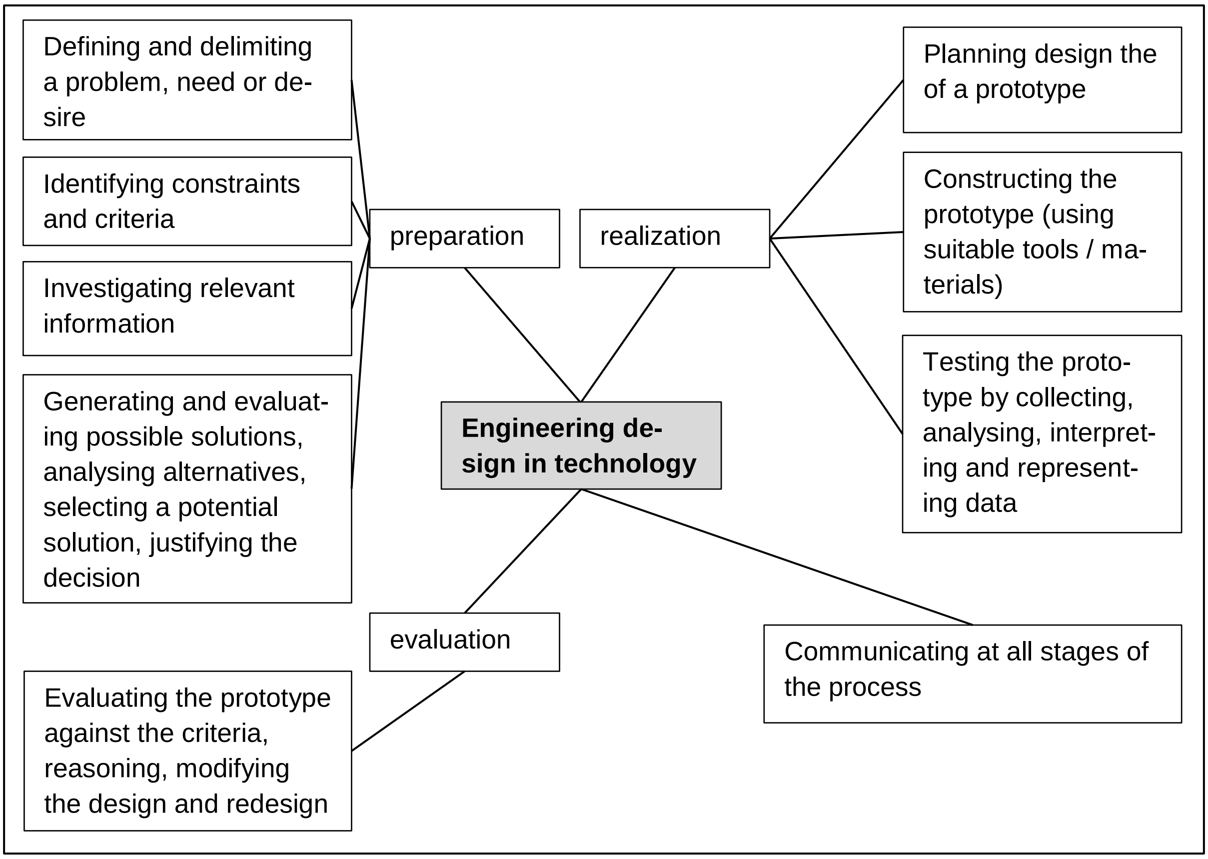

Figure 15: Engineering design competence framework (based on Rönnebeck & Ropohl, 2014).

The following example of a learning progression for the sub-competence "investigate relevant information" is thought to serve as an example for the local working groups. The example is inspired by learning progressions developed in Switzerland (Beerenwinkel & Labudde, 2011; Streit and Schick, 2011), and by the Swiss educational standards in science and Mathematics (EDK, 2011). The national educational standards have been elaborated over a period of several years, are supported very broadly, and have been approved by the Swiss Conference of Cantonal Ministers of Education (EDK). The specific differences between inquiry in science and inquiry in Technology have been adapted from National Research Council, 2012.

Local working groups who develop their own learning progressions should keep in mind that students' levels of competence may not evolve linearly or step - by - step as it may look like in the example here. More exemplary learning progressions for 'engineering design in technology' can be found in the appendix.

Sub-competences	Exemplary basic standards for grade 4 technology students	Exemplary basic standards for grade 6 technology students	Exemplary basic standard for grade 9 technology students	Exemplary basic standard for grade 12 technology students
Investigate relevant information	Students can, guided by the teacher, search and collect information in relation to a specific question or topic from a given, appropriately edited selection of media. They can compile these pieces of information guided by the teacher. They can distinguish and read, guided by the teacher, different forms of data presentation such as simple tables or diagrams.	Students can, guided by the teacher, search and collect information in relation to a specific question or topic from a *given selection* of media. They can *process* these pieces of information guided by the teacher. They can distinguish and *read* different forms of data presentation such as simple *graphs,* tables, or diagrams.	Students *can search and collect* information in relation to a specific question or topic from a given selection of media. They can process these pieces of information *partly* guided by the teacher. They can distinguish and read different forms of data presentation such as *graphs, tables, or diagrams*.	Students can search and collect information in relation *to a specific question or topic*. They *can process* these pieces of information. They can distinguish and read different forms of data presentation such as graphs, tables, or diagrams *as well as graphical representations of processes or relationships such as flowcharts or concept maps.*

Table 6: Exemplary learning progressions for engineering design in technology education. Based on EDK, 2011; Beerenwinkel & Labudde, 2011 and National Research Council, 2012.

8.5 Argumentation

This chapter was written by Demetris Koursaris, Elena Siakidou, Nikos Papadouris, Costas Constantinou. With additions by Jan Alexis Nielsen.

The development of argumentation skills is recognized as a key aspect of scientific literacy and is widely recognized as an important skill for citizenship and also as a significant learning objective of science teaching (Jimenez-Aleixandre et al. 2000; Erduran, Simon & Osborne, 2004; NRC, 2012). Argumentation, as a core cross-disciplinary competency in teaching and learning, has wider applicability in different domains such as science, mathematics and technology.

Argumentation refers to the process of constructing and negotiating arguments (Osborne et al., 2004), either individually or cooperatively, which can be expressed either verbally or in writing (Driver et al., 2000). An argument must be stated clearly by the use of a claim, a position or a conclusion and be properly supported with evidence (Jimenez–Aleixandre et al. 2000).

Argumentation is a composite skill that can be analyzed in two separate categories, namely argumentation practices and metaknowledge on argumentation.

The first category refers to the argumentation practices that are taken into consideration when a person engages in argumentation and it is divided into three constituent sub-competences:
a) constructing arguments
b) analyzing arguments and
c) communicating arguments.

The first sub-competence, ***constructing arguments,*** includes the ability to state a claim, an opinion or a conclusion for an issue, a topic or a problem (Jimenez-Aleixandre et al., 2002; Zohar & Nemet, 2002; Kuhn & Udell, 2003) which must be justified using various data, justifications/reasons (Chin & Osborne, 2010; Venville & Dawson, 2010).

Analyzing arguments refers to the process of the identification and evaluation of both individual and dialogic argumentation. Specifically, individual arguments can be analyzed to the constituent components (structural elements) (Toulmin, 1958; 2003). In dialogic argumentation the three main components (argument, counter-argument, and rebuttal) and the different kinds/types of the counter-arguments (alternative counter-arguments and counter-argument critique) can be identified (Kuhn, 1991; 1993; Kuhn et al., 1997; Kuhn et al., 2008).). In dialogic argumentation, it is crucial to take into account the dialectical features of the argumentation – such as the relevant context in which a particular utterance was made (e.g. a given utterance may be connected to an utterance made by another speaker a substantial amount of time ago) (Nielsen, 2011).

The sub-competence of ***communicating arguments*** consists of the abilities associated with accurate and effective communication (NRC, 1996). These include expressing ideas, reviewing information and summarizing data depending on the target audience, using appropriate language, speaking clearly and logically and responding appropriately to others arguments.

The second category refers to argumentation as a metaknowledge competence (Kuhn, 1999).). For science, mathematics and technology education, this is particularly important since students must learn to use science content legitimately in arguing about e.g. societal issues (Nielsen, 2012a, 2012b) and e.g. to distinguish between the pragmatic and epistemic function of ‘explanations’ vis-á-vis ‘arguments’ (Osborne & Patterson, 2011). Further, much argumentation in science education will be argumentation about what to do (practical argumentation) and not just what is true. This is an issues that students must take into account while discussing with peers and when constructing own arguments (Nielsen, 2013). Metaknowledge comprises three types, one about declarative knowledge (metacognitive knowing) and the other about procedural knowledge (metastrategic knowing) (Kuhn & Pearsall, 1998). The third metaknowledge type is epistemological knowing, which involves knowing about knowledge in general.

Metacognitive knowing is related to the knowing (know-what) of the constituent components (structural elements) and the role and importance of each of them in an argument.
Metastrategic knowing is connected to the implementation of the strategies (know-how) and the understanding and awareness of its nature (Kuhn & Pearsall, 1998).
Epistemological knowing is refers to the epistemic or pragmatic dimension of cognitive competence of argumentation (know-be) regarding the quality of arguments per se (relevance, sufficiency, acceptability of the premises provided by sufficient evidence) and in terms of a process.

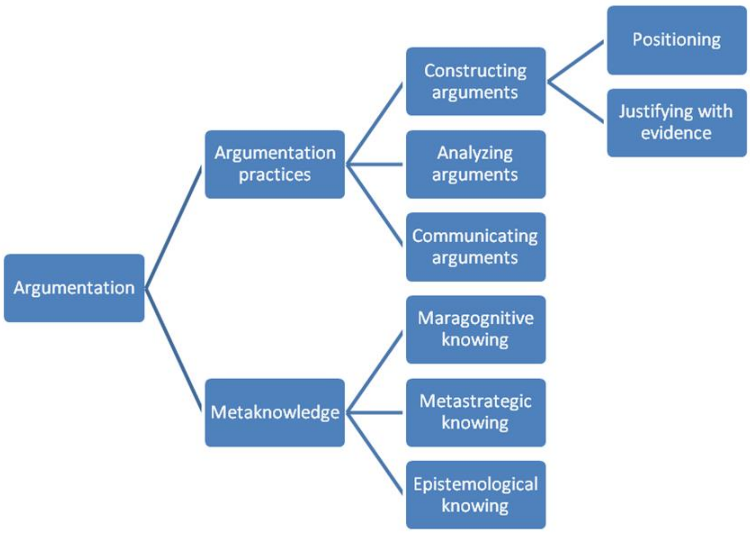

Figure 16: Representation of the constituent components of the argumentation competence

Sub-competence	Description
Constructing arguments	- State of a claim (opinion or conclusion) and a counter-claim - Justifying claim/counter-claim with evidence (grounds/reasons/justifications) - Construct integrated arguments using claim, grounds/reasons/justifications and rebuttals
Analyzing arguments	- Analyze grounds into data, warrant, backing - Analyze arguments into constituent components (structural elements) (claim, data, warrant, backing, rebuttal) - Identify the elements of dialogic argumentation (argument, counter-argument, and rebuttal) - Identify different types of counter-argument (counter-alternative and counter-critique)
Communicating Arguments	- Discuss a topic - Ability to listen carefully their peer - Construct arguments depending on the target audience using appropriate evidence and language - Debate

Meta-knowledge	- Metacognitive knowing
	  - Knowing the role and importance of each specific constituent component of an argument
	- Metastrategic knowing
	  - Knowing how to implement the dialogic argumentation elements
	- Epistemological knowing
	  - Differentiation between the scientific data and personal beliefs
	  - Differentiation between the primary and secondary sources of data
	  - Recognition that the argument should be acceptable to the arguer or the audience to which the argument is directed
	  - Identification of the need to provide sufficient evidence for the conclusion to be drawn

Table 7: Description of argumentation sub-competences.

8.6 Modelling

This chapter was written by Christiana Nicolaou, Nikos Papadouris, Costas P. Constantinou.

Modelling is the process of constructing and using scientific models (Hestenes, 1987) and it is considered an integral part of science (NRC, 2012). Efforts to design modelling-based learning (MBL) instruction have relied on a theoretical framework about the modelling competence, which analyses its constituent components into two broad categories, namely *modelling practices and meta-knowledge* (figure 17). Underlying this framework is the idea that student modelling competence can emerge as a result of active participation in specific modelling practices and can be reinforced by meta-knowledge about models and modelling (2009). Model construction (Stratford, Krajcik, & Soloway, 1998); model use (NRC, 2012); comparison between models (Penner, Giles, Lehrer, & Schauble, 1997); model revision (Schwarz & White, 2005) and model validation have been identified as the practices in which students can be usefully engaged during modelling. Meta-knowledge, on the other hand, is analysed into the metacognitive knowledge about the modelling process; this refers to student ability to explicitly describe and reflect on the actual process of modelling, but also on the knowledge about the nature and the purpose of models (Schwarz & White, 2005). In other words, this framework posits what scientists do during modelling and at the same time what we want students to do, so as to be modelling competent.

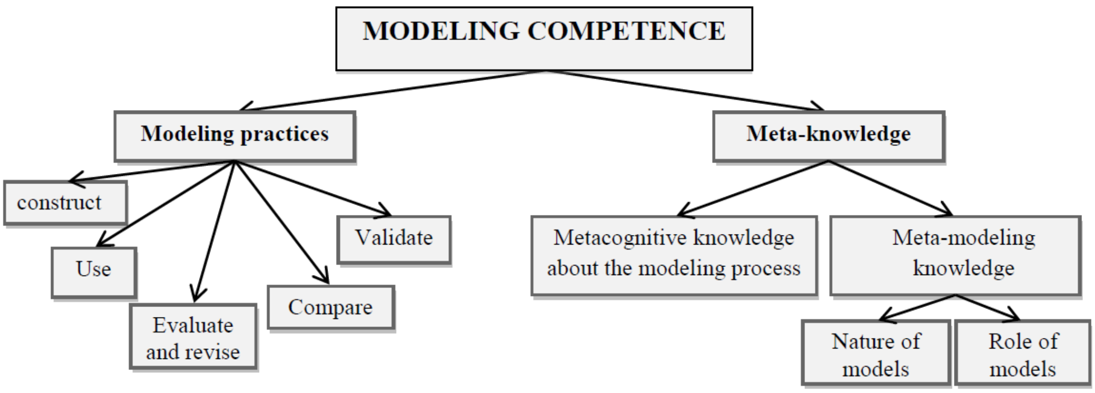

Figure 17: Modelling Competence Framework (Papaevripidou, Nicolaou, & Constantinou, 2014).

Each component of the modelling competence can be analysed into a series of levels of increased sophistication. These levels form a progression for the learning objective of interest (which is also the focus of assessment). That is, in using an assessment instrument for a specific component of the modelling competence, this progression would specify a series of increasingly more informed categories of response that could be presumably encountered in students' responses.

The levels associated with each aspect were derived from an empirical study we have undertaken for this purpose (Karnaou, Nicolaou, Petrou, & Constantinou, 2014). The coding scheme used for analysing the data concerning each modelling component is shown in Table 8. This coding scheme also reflects the desired level of students' performance for each modelling competence component shown in Figure 17. For example, if students are to be considered competent with respect to the model evaluation and revision practice, they need to be able to evaluate and revise a given model in terms of its representational, interpretive and predictive power.

Definition	*Desired level of students' ability*
1. MODELING PRACTICES	
MODEL CONSTRUCTION: Develop an external representation of a physical phenomenon which consists of objects, variables, processes and interactions among these elements. All these elements should obey to an underlying mechanism, which will rule the model.	Learner constructs models according to their (a) representational power (Objects, variable quantities, processes, relations), (b) interpretive power (the story behind the model) and (c) predictive power (the model allows for making predictions)
MODEL USE: Run the model in order to explore possible changes in particular aspects of the phenomenon, investigate the conditions under which observable changes happen and thereby formulate predictions.	Learner correctly chooses a model or data to predict the evolution of the phenomenon under study
MODEL COMPARISON: Select the most and the least appropriate model that represents a phenomenon under study based on certain criteria; (i) plausibility, (ii) accuracy, and (iii) facility of the model to formulate and test predictions.	Learner compares models and chooses the best one according to its (a) representational, (b) interpretive and (c) predictive power
MODEL EVALUATION AND REVISION (i) contrast a model with its corresponding phenomenon, (ii) evaluate it on the basis of the absence or presence of a model's basic components (e.g., objects, variables, process, interactions), and (iii) pose ways of how the missing parts could be integrated in the revised model.	Learner evaluates and revises a given model with respect to its representational, interpretive and predictive power
MODEL VALIDATION seek evidence that supports the connection between the model and the corresponding phenomena. This can be achieved by using the model to formulate a range of predictions and then seeking empirical confirmation for those predictions. It can also be achieved by using the model to formulate hypotheses about connections between variables and again seeking empirical validation. Finally, it is also possible to apply a model to a new phenomenon in the same class, in order to explore the extent to which it has broader applicability.	Learner validates the model through applying it in a total new case of a phenomenon (e.g., a phenomenon of the same class) and studies if the model fits in this new case
2. METAKNOWLEDGE	
Meta-cognitive knowledge about the modeling process:	Learner identifies the major steps of the modeling process: (1) Study of the data (phenomenon), (2) Identification of model components, (3) Model construction, (4) Return to the data for comparison purposes, (5) Identification of new relations or model components, (6) Model revision
Meta-modeling knowledge: describe and reflect on the major steps of the modeling-based learning cycle (Figure 2). This also includes the learner's ability to plan, monitor and evaluate activities that are designed to implement the cycle, as well as learner's development of epistemic awareness regarding the nature and the purpose or utility of models	-Nature of models: Learner identifies model as a human product, and as an invention which is based on scientific theoretical rules or established expertise. -Purpose of the models: Learner identifies the 3 distinct roles of a model: (1) Representation of the phenomenon, (2) Interpretation of the phenomenon, (3) Prediction of the future evolution of the phenomenon.

Table 8: Subcompetences of modelling.

8.7 Innovation

This chapter was written by Jan Alexis Nielsen.

Innovation teaching (or teaching for innovation competence) is basically just an extension of inquiry teaching.

Innovation teaching activates the students in processes where they have to work on an authentic issue from a practice in order to construct suggestions/ideas that could *improve* on that issue for practice.

In that process, students work in a way that is very similar to inquiry teaching, because they have to identify problems/questions/issues, generate ideas/hypotheses, design and plan investigations of the issue/practice, analyze and evaluate their findings and communicate the findings.

The defining criteria of innovation teaching is that students are not "just" exploring/investigating a phenomenon or process in order to learn about it, they explore/investigate it in order to reflect and work on how society (or a practice within society) can be improved.

Here are two examples of typical innovation processes that show the resemblance to inquiry processes:

Example of a typical inquiry process	**Example of a typical innovation process**	
	Version 1: First inquiry then innovation	**Version 2: Integrated inquiry and innovation**
Students are presented with an issue about chemicals in playground equipment ↓ Students make hypotheses and predictions about chemicals used in playground equipment ↓ Students designs and plans ways to test different types of equipment ↓ Students collect data ↓ Students analyze and evaluate data ↓ Students communicate their results	Students are presented with an issue about chemicals in playground equipment ↓ Students make hypotheses and predictions about chemicals used in playground equipment ↓ Students designs and plans ways to test different types of equipment ↓ Students collect data ↓ Students analyze and evaluate data ↓ Students communicate their results ↓ Students generate ideas on how to find out how the equipment at the local kindergarten playground can be made more safe/environment friendly ↓	Students are presented with an issue about how to make the playground equipment at a local kindergarten more safe/environmental friendly ↓ Students make hypotheses and predictions about which kind of materials should be used for making playground equipment ↓ Students designs and plans ways to test different types of equipment and ways to collect information about the needs of the users of playgrounds ↓ Students collect data from experiments with materials and from interviews with users ↓ Students analyze and evaluate data and develop solutions for making the playground safer ↓ Students communicate their

	Students present their plans to each other and revise and improve their plans 🡻 Students collects information from e.g. leaders, pedagogues and children in order to make informed suggested solutions 🡻 Students develop solutions for making the playground safer 🡻 Students present their solutions to the users (leaders, pedagogues and children)	results (e.g. to users of the local playground)

Table 9: Two examples of typical innovation processes that show the resemblance to inquiry processes.

Innovation competence is the ability to (individually, or in collaboration with others,)

- apply relevant knowledge in order to generate ideas for solutions to issues from an existing practice,
- to assess these ideas in terms of their utility, realizability, and value-creation,
- to realize selected ideas (e.g. in draft or sketch form),
- and to communicate ideas to different stakeholders.

Innovation is not entrepreneurship:
'Innovation' should be distinguished sharply from 'entrepreneurship': while the essence of innovation in almost all definitions is about creating something new that has a value (in the broadest possible sense), entrepreneurship is about transforming something into economic gain (Nielsen, Rump, & Christiansen, 2013)

Subcompetences:
By most understandings of innovation it will be difficult to validly assess a students' real ability to innovate. For example, how could a teacher or other stakeholders assess whether a product or an idea generated by a student really adds value to or improves an existing practice in the world? The person doing the assessment would need to be a fluent navigator of that practice – which in practice is unrealistic – and it would in any case be difficult to make authoritative predictions about whether the particular product or idea will add value to or improve the practice in the long term.

These challenges can be met by focusing on assessing *innovation competence* – understood as a set of skills and sub-competences that together may be designated as necessary but not sufficient for innovation. Based on a recent research study involving experienced innovation teachers (See Nielsen, in press), it is possible to flesh out preparatory innovation competence with the five sub-competencies which, in turn, can each be fleshed out in terms of skills (see table below adopted from Nielsen, in press):

- **Creativity competence:** This competence represents the student's ability to generate ideas that are not just the usual idiosyncratic ideas of the student. Instead of choosing the first idea that springs to mind, the student can work on generating a range of ideas, either by herself or together with others. Further, this competence represents the student's ability to sort, prioritize and select among a range of ideas in terms of the potential utility, value-creation, or realizability of the idea. This also includes the student's ability to improve on and further develop own ideas or ideas of others.

- **Collaboration competence:** This competence represents the student's ability to work fruitfully together with others. The student must be able to work with different collaborators (maybe even from outside the classroom) – not just the same peers that the student is used to collaborate with. Also, the student must take responsibility for finished her own tasks in a group, and she must be able to facilitate that her collaborators can perform their tasks well (this also includes participation in planning the group work)

- **Navigation competence:** This competence represents the student's ability to handle information and knowledge. Often, the information available when dealing with authentic issues can be diverse, disparate, and plentiful. The student needs to handle the stream of information in a functional way by making the knowledge available operationalizable. This involves in the first place that the student can translate the issue in practice to a discipline or knowledge field. It also involves sorting, structuring and prioritizing information, and it involves identifying which information is still needed in order to do the task.

- **Action/Implementation competence:** This competence represents the student's ability to take risks and actions based on an informed decision. The key feature of action competence is that student does not stop at the level of an idea, but that she takes action to somehow bring that idea to life. For example, if a group of students talk about a way of designing a playground without using toxic chemical materials and then by themselves present a sketch of their ideas to a local kindergarten principal in order to improve the utility of their idea, that could be an indicator of action competence. Or if a student at point in the work process cuts through the discussion among the group because she realizes that the group has to make a decision because they need to finish their task, that could also be an indicator of action competence. At lower levels this competence could represent just that the student maintains her activity level throughout the work process. At higher levels this competence could represent that the student is driven enough to get outside her comfort zone and contact stakeholders outside of the classroom.

- **Communication competence:** This competence represents the student's ability to communicate to different types of audiences/target groups, based on a relatively (for her age group) skilled analysis of what and how to communicate a message/topic/idea.

Assessment criteria (sub-competences)	
creative competence	The student is open towards own ideas and the ideas of others in idea-generating processes - e.g. by developing or nurturing the development of non-idiosyncratic ideas.
	The student works with ideas in a critical fashion - e.g. by sorting and selecting ideas.
	The student independently interprets a task or problem issue - e.g. by finding problem issues in her own life or by finding a novel / non-idiosyncratic interpretation of a given task.
collaboration competence	The student takes responsibility for won tasks, and facilitates that the group finishing its tasks - e.g. by using what she knows about group dynamics to help organize the group's work.
	The student is inclusive and flexible in collaboration - e.g.by being able to work with new partners and / or by utilizing the complementary competences of others.
navigation competence	The student understands the problem issue - e.g. by decoding the problem issue in disciplinary terminology.
	The student masters complex work processes - e.g. by making balanced decisions about what the group should do in a specific phase of a project.
	The student handles knowledge and information in a functional fashion - e.g. by sorting, structuring, and prioritizing information.
action competence	The student takes risks and put oneself and / or others into play - e.g. by taking steps to go from idea to action.
	The student makes informed decisions - e.g. by analysing the possible consequences of s specific action.
	The student actively seeks information - e.g. by contracting sources outside her usual comfort zone.
communication competence	The student assesses how to communicate - e.g. by analysing how to communicate a specific message to a specific target audience in a specific situation.
	The student masters communication techniques - e.g. by communicating in multiple modalities / formats.
	The student communicates engagingly and convincingly - e.g. by consciously using rhetorical argumentation.

Table 10: Sub-competences in the 'innovation competence'. Taken and slightly adapted from Nielsen, in press.

References

Adler, M. (1982). *The Paideia proposal*. New York: Macmillan

Arter, J. A., & McTighe, J. (2001). *Scoring rubrics in the classroom: Using performance criteria for assessing and improving student performance.* Thousand Oaks: Corwin Press.

Black, P., Harrison, Ch., Lee, C., Marshall, B., and Wiliam, D. (2003): *Assessment for learning: putting it into practice*. Open University Press, London.

Black, P., Harrison, Ch., Lee, C., Marshall, B., and Wiliam, D. (2004): *Working inside the black box: assessment for learning in the classroom.* Phi Delta Kappan, Sept. 2004.

Black, P., Harrison, Ch. (2004): *science inside the black box*. GL Assessment, London.

Beerenwinkel, A., & Labudde, P., (2011). *Kompetenzraster Naturwissenschaften.* Bildungsraum Nordwestschweiz. Regierungsausschuss Bildung. Retrieved from http://www.fhnw.ch/ph/zntd/downloads.

Bell, B., & Cowie, B. (2001). *Formative assessment and science education*. Dordrecht: Kluwer.

Bernholt, S., Rönnebeck, S., Ropohl, M., Köller, O., Parchmann, I. (2013). *Report on current state of the art in formative and summative assessment in IBE in STM-Part 1.* Kiel.

Bräuer, G. (1998). Portfolios: Lernen durch *Reflektieren. In: Informationen zur Deutschdidaktik*, 22/4, 80-91.

Burke, K. (2006). *From standards to rubrics in 6 steps.* Heatherton, Victoria: Hawker Brownlow Education.

Chin, C., & Osborne, J. (2010). Students' questions and discursive interaction: Their impact on argumentation during collaborative group discussions in science. *Journal of Research in science Teaching*, 47(7), 883-908.

Christensen, T. S. (2004). *Integreret Evaluering – En undersøgelse af den fagligt evaluerende lærer-elevsamtale som evalueringsredskab i Gymnasial Undervisning* (PhD Dissertation). University of Southern Denmark, Odense.

Darsø, L. (2011). *Innovationspædagogik [Innovation pedagogy]*. Copenhagen: Samfundslitteratur.

DiCerbo. K. E. & Behrens, J. T. (2014) *Impacts of the Digital Ocean*, London: Pearson.

Dolin, J. (2012). *Assess Inquiry in science, Technology and Mathematics Education: ASSIST-ME proposal.* University of Copenhagen.

Dolin, J. (2014). *Formative and summative assessment.* University of Copenhagen.

Duschl, R.A. (2003). Assessment of inquiry. In J.M. Atkin & J.E. Coffey (Eds.), *Everyday assessment in the science classroom* (pp. 41–59). Washington, DC: National science Teachers Association Press.

Duschl, R.A., & Gitomer, D.H. (1997). Strategies and challenges to changing the focus of assessment and instruction in science classrooms. *Educational Assessment*, 4, 37–73.

Driver, R., Newton, P. & Osborne, J. (2000). Establishing the Norms of Scientific Argumentation in Classrooms. *science Education*, 84, 287-312.

EDK, (2011). *Grundkompetenzen für die Naturwissenschaften - Nationale Bildungsstandards*. Retrieved from: http://www.edk.ch/dyn/12930.php

EDK, (2011). *Grundkompetenzen für die Mathematik - Nationale Bildungsstandards.* Retrieved from: http://www.edk.ch/dyn/12930.php

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin’s Argument Pattern for studying science discourse. *science Education*, 88(6), 915–933.

Fagerberg, J. (2006). Innovation: A Guide to the Literature. In Jan Fagerberg, David C. Mowery & Richard R. Nelson (Eds.), *The Oxford handbook of innovation* (pp. 1-26). Oxford: Oxford University Press.

Hafner, J. C., & Hafner, P. M., (2003). Quantitative analysis of the rubric as an assessment tool: an empirical study of student peer-group rating. *International Journal of science Education, 25,* 1509-1528.

Hanrahan, S. J., & Isaacs, G. (2001). Assessing self- and peer-assessment: The students' views. *Higher Education Research and Development, 20*, 53–70

Harlen, W. (2007). Holding up a mirror to classroom practice. *Primary science Review*, 100, 29–31.

Harlen, W. (2013). *Assessment & inquiry-based science education: issues in policy and practice.* Global Network of science Academies (IAP) science Education Programme (SEP). Retrieved from http://www.interacademies.net/File.aspx?id=21245

Hartig, J., Klieme, E., & Leutner, D. (2008): *Assessment of competences in educational contexts*. Göttingen: Hogrefe.

Hestenes, D. (1987). Towards a Modelling Theory of Physics Instruction. American Journal of Physics, 55(5), 440-454.

Hobel, P., & Christensen, T.S. (2012). Innovative evner og de gymnasiale uddannelser [Innovative abilities and the upper secondary education programmes]. In M. Paulsen & S.H. Klausen (Eds.), *Innovation og Læring [Innovation and Teaching]* (pp. 49-73). Aalborg.

Iordanou, K. (2010). Developing argument skills across scientific and social domains. *Journal of Cognition and Development*, 11 (3), 293-327.

Jiménez -Aleixandre, M. P., Rodriguez, A. B., & Duschl, R. A. (2000). 'Doing the lesson' or 'doing science': Argument in high school genetics. *science Education*, 84(6), 757-792

Jiménez-Aleixandre, M. P., & Pereiro Munoz, C. (2002). Knowledge producers or knowledge consumers? Argumentation and decision making about environmental management. *International Journal of science Education*, 24, 1171–1190.

Karnaou, P., Nicolaou, C. T., Petrou, T., & Constantinou, C. P. (2014). *Assessment of Learner's Constructed Models and Modelling Competence*. Paper presented at the EdMedia2014.

Kocakülah, M. S. (2010). Development and application of a rubric for evaluating students' performance on Newton's laws of motion. *Journal of science Education and Technology, 19,* 146-164.

Kemper, S., and Tatzki, V. (2010). *Entwicklung eines Bewertungsschemas zur Leistungsbepunktung von Lernprozessgraphiken und Protokollbögen.* Vertiefungsarbeit im Fach Chemiedidaktik, Universität Duisburg-Essen.

Kuhn, D. (1991). *The skills of argument*. Cambridge University Press.

Kuhn, D. (1993). science as argument: Implications for teaching and learning scientific thinking. *science Education*, 77(3), 319 - 337.

Kuhn, D., Shaw, V., & Felton, M. (1997). Effects of dyadic interaction on argumentive reasoning. *Cognition and Instruction*, 15, 287–315.

Kuhn, D., & Pearsall, S. (1998). Relations between metastrategic knowledge and strategic performance. *Cognitive Development*, 13, 227–247.

Kuhn, D. (1999). *Metacognitive development*. In L. Balter & C. Tamis Le-Monda (Eds.), Child psychology: A handbook of contemporary issues. Philadelphia: Psychology Press.

Kuhn D., Goh W., Iordanou K., & Shaenfield D. (2008). Arguing on the Computer: A Microgenetic Study of Developing Argument Skills in a Computer-Supported Environment. *Child Development*, 79 (5), 1310 – 1328.

Kuhn, D., & Udell, W. (2003). The development of argument skills. *Child Development*, 74 (5), 1245–1260.

Leahy, S., Lyon, Ch., Thompson, M., and Wiliam, D. (2005). *Classroom assessment: minute by minute, day by day.* Assessment to promote learning, Vol. 63 No. 3, pp.19-24.

Lin, S. S. J., Liu, E. Z. F., & Yuan, S. M. (2001). Web-based peer assessment: feedback for students with various thinking styles. *Journal of Computer Assisted Learning, 17,* 420-432.

Lindsay, C., & Clarke, S. (2001). Enhancing primary science through self– and paired–assessment. *Primary science Review, 68*, 15–18.

Mazur, E., (1997). *Peer Instruction: A User's Manual.* New Jersey: Prentice Hall.

Moskal, B. M. (2003). *Recommendations for developing classroom performance assessments and scoring rubrics.* Practical Assessment, Research & Evaluation8(14).

Muijs, D., Reynolds, D. (2011). *Effective teaching. Evidence and practice.* SAGE: London.

Nielsen, J. A. (2011). Dialectical features of students' argumentation: A critical review of argumentation studies in science education. *Research in Science Education, 43*, 371–393.

Nielsen, J. A. (2012a). Arguing from Nature: The role of 'nature' in students' argumentations on a socio-scientific issue. *International Journal of Science Education, 34*, 723–744.

Nielsen, J. A. (2012b). Science in discussions: An analysis of the use of science content in socioscientific discussions. *Science Education, 96*, 428–456.

Nielsen, J. A. 2013. Delusions about evidence: On why scientific evidence should not be the main concern in socioscientific decision making. *Canadian Journal of Science, Mathematics and Technology Education*, 13(4): 373–385.

Nielsen, J.A., Rump, C.Ø., & Christiansen, F.V. (2013). *Science Education For Innovation: A new way of connecting science teaching with real societal needs?* Paper presented at the ESERA Conference.

Nielsen, J.A. (in press). Assessment of innovation competency: A thematic analysis of upper secondary school teachers' talk. *Journal of Educational Research.*

National Research Council. (1996). *National science Education Standards*. Washington, DC: The National Academies Press.

National Research Council, 2012. *A framework for K-12 science Education. practices, Crosscutting Concepts, and Core Ideas.* The national Academies Press, Washington D.C. Retrieved from http://www.nap.edu/catalog.php?record_id=13165.

OECD, 2006. *Assessing Scientific, Reading and Mathematical Literacy: A Framework for PISA 2006.* Paris: OECD Publishing.

OECD (2013). *PISA 2012 Assessment and Analytical Framework. Mathematics, Reading, science, problem solving and financial literacy.* Retrieved from http://www.oecd.org/pisa/pisaproducts/PISA%202012%20framework%20e-book_final.pdf.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in science Teaching*, 41(10), 994–1020.

Osborne, J., & Patterson, A. (2011). Scientific argument and explanation: A necessary distinction? *Science Education*, **95**(2), 627–638.

O'Sullivan, D., & Dooley, L. (2009). *Applying Innovation*. London: Sage Publications Ltd.

Papaevripidou, M., Nicolaou, C. T., & Constantinou, C. P. (2014). On Defining and Assessing Learners’ Modelling Competence in science Teaching and Learning. Paper presented at the Annual Meeting of American Educational Research Association (AERA), Philadelphia, Pennsylvania, USA.

Penner, D. E., Giles, N. D., Lehrer, R., & Schauble, L. (1997). Building Functional Models: Designing an Elbow. *Journal of Research in science Teaching, 34*(2), 125-143.

Pihlgren A. (2007). The Features of Socratic Seminar. Linkoping University Electronic press, 159–165.

Polite, V. C., & Adams, A. H. (1997). Critical thinking and values clarification through Socratic seminars. *Urban Education*, 32, 256–278.

Rönnebeck, S., Ropohl, M., & Köller, O. (2013). *Report of outcomes of the expert workshop on formative assessment in STM and IBE (No. D 2.6).* Kiel.

Rönnebeck, S., Ropohl, M., Bernholt, S., Köller, O., Parchmann, I. (2013). *Recommendation report from D2.1 - D2.6 to be used as a foundation for WP4 and 5 (No. D 2.7).* Kiel.

Ropohl, M., Rönnebeck, S., Bernholt, S., & Köller, O. (2013). *A definition of inquiry-based STM education and tools for measuring the degree of IBE (No. D 2.5).* Kiel.

Ruiz-Primo, M.A., Furtak, E.M (2006a). Exploring teachers' informal formative assessment practices and students' understanding in the context of scientific inquiry. *Journal of research in science Teaching*. 44 (1), p. 57 - 84.

Ruiz-Primo, M.A., Furtak, E.M (2006b). Informal formative assessment and scientific inquiry: exploring theachers' practices and student learning. *Educational Assessment* 11 (3& 4), 205-235.

Ruiz-Primo, M.A., Furtak, E.M (2004). Informal formative assessment of students' understanding of scientific inuiry. CSE Report 639. University of Californina.

Rump, C.Ø., Nielsen, J.A., Andersson, P.H., & Christiansen, F.V. (2013). *A framework for teaching educators to teach innovation, P*. Paper presented at the The Annual conference for the European Society for Engineering Education (SEFI).

Sadler, R. (1989). Formative assessment and the design of instructional systems. *Instructional science,* 18: 119-44.

Schwarz, C., & White, B. (2005). Metamodelling Knowledge: Developing Students’ Understanding of Scientific Modelling. *Cognition and Instruction, 23*(2), 165–205.

Shavelson, R.L., Young, D.B., Ayala, C.C, Brandon, P.R., Furtak, E.M., Ruiz-Primo, M.A, Tomita, M.K., Yin, Y. (2008). On the impact of curriculum-embedded formative assessment on learning: a collaboration between curriculum and assessment developers. *Applied Measurement in Education*, 21: 295 - 314.

Shavelson, R. (2011): *An approach to testing and modelling competence.* Paper presented at the Bad Honnef Conference on Teachers’ Professional Knowledge, May 6-7.

Sluijsmans, D. M. A. (2002). *Student involvement in assessment, the training of peer-assessment skills.* Interuniversity Centre for Educational Research.

Smit, R., & Birri, Th., (2014). Assuring the quality of standards-oriented classroom assessment with rubrics for complex competencies. *Studies in Educational Evaluation* (2014), http://dx.doi.org/10.1016/j.stueduc.2014.02.002

Stewart, J., Milt Th., (1995). "Dialogic Listening: Sculpting Mutual Meanings," in *Bridges Not Walls*, ed. John Stewart, 6th edition, New York: McGraw- Hill, 184-201.

Streit, Ch., & Schick, G. (2011). *Kompetenzraster Mathematik.* Bildungsraum Nordwestschweiz. Regierungsausschuss Bildung. Retrieved from www.fhnw.ch/ph/zntd/Math_Kompetenzraster.pdf.

Stratford, S. J., Krajcik, J., & Soloway, E. (1998). Secondary Students' Dynamic Modelling Processes: Analyzing, Reasoning about, Synthesizing, and Testing Models of Stream Ecosystems. *Journal of science Education and Technology 7*(3), 215 - 234.

Topping, K. (1998). Peer assessment between students in colleges and universities. *Review of Educational Research, 68,* 249–276.

Topping, K. J. (2003). Self and peer assessment in school and university: reliability, validity and utility. In M. Segers, F. Dochy & E. Cascaller (Eds.), *Optimising new modes of assessment: in search of qualities and standards* (pp. 55–87). The Netherlands: Kluwer Academic Publishers.

Topping, K., Smith, F. F., Swanson, I., & Elliot, A. (2000). Formative peer assessment of academic writing between postgraduate students. *Assessment and Evaluation in Higher Education, 25,* 149-169.

Toulmin, S. E. (2003). *The uses of argument* (updated ed.). Cambridge, England: Cambridge University Press.

Tsivitanidou, O., Zacharia, Z. C. & Hovardas, A. (2011). High school students' unmediated potential to assess peers: unstructured and reciprocal peer assessment of web-portfolios in a science course. *Learning and Instruction, 21*, 506-519.

Venville, G. J., & Dawson, V. M. (2010). The impact of a classroom intervention on grade 10 students' argumentation skills, informal reasoning, and conceptual understanding of science. *Journal of Research in science Teaching*, 47(8), 952-977.

Wiliam, D., (2011). *Embedded formative assessment*. Bloomington IN: Solution Tree Press.

Wiliam, D., & Thompson, M. (2007). Integrating assessment with instruction: What will it take to make it work? In C. A. Dwyer (Ed.), *The future of assessment: Shaping teaching and learning* (pp. 53–82). Mahwah, NJ: Erlbaum.Zohar, A. & Nemet, F. (2002). Fostering Students' Knowledge and Argumentation Skills Through Dilemmas in Human Genetics. *Journal of Research in science Teaching*, 39 (1), 35-62.

Appendix

A.1 Sub-competence - data collection about student learning - assessment method- combinations for "investigations in science"

Means of data collection about student learning			Feedback methods			
			On-the-fly	Marking (grading and written comments)	Self- and peer-assessment	Open classroom discussion and structured classroom dialogue
	Written data	Multiple Choice	135			135 **PE1.2 (subcompetence 4)**
		Written answer to open question	13568 **PE1.7 (subcompetences 5,6,7)**	13568	13568 **PE1.1 (subcompetence 1)**	13568
		Written assignment	13568	13568	13568	13568
		Sketch	567	567	567	567
		Poster	135678	135678	135678	135678
		Concept map, mind map	567	567	567	567
		Report (lab report, excursion report)		1345678 **PE1.5 (subcompetences 4,5,6,8)**	1345678	
		Notebook, lab journal	45	45	45 **PE1.4 (subcompetence 4)**	
		Portfolio		135678		
	Performance-based data	Observation of performance / video	24		24	
		Student protocol	24	24	24	24 **PE1.3 (subcompetence 3, 4)**
		Artefacts (constructed device, …)	47		47	47
	Oral data	Oral presentation	134568	134568	134568	134568
		Debate, discourse, role-play	134568	134568	134568	134568
		Assessment dialogue				134568 **PE1.6 (subcompetences 5,6,7,8)**
		Interview, accountable talk				134568
		Audio tapes / video tapes		134568	134568	134568
	Electronically collected data	…	Compare to chapters 5.4 and 7			
		…				
		…				
		…				

Key for the subcompetences:

1) identifying the question,
2) searching for information,
3) formulating hypotheses or making predictions,
4) planning and carrying out experiments,
5) analyzing, interpreting and evaluating data and results.
6) developing explanations,
7) constructing and using models,
8) engaging in argumentation from evidence.

Table 11. Feedback methods and means of data collection put in relation for the 'investigations in science' competence (the later adapted from Bernholt et al., 2013). Combinations that might be commonly used in daily teaching are marked blue. Bold numbers indicate that this combination of sub-competence, means of data collection and feedback method is illustrated by a paradigmatic example PE.

A.2 Sub-competence - data collection about student learning - assessment method combinations for "problem - solving in mathematics"

Means of data collection about student learning			Feedback methods: On-the-fly	Feedback methods: Marking (grading and written comments)	Feedback methods: Self- and peer-assessment	Feedback methods: Open classroom discussion and structured classroom dialogue
	Written data	Multiple Choice			239	239
	Written data	Written answer to open question	123456789	123456789	123456789	123456789
	Written data	Written assignment		123456789	123456789 **PE2.6**	
	Written data	Sketch	123456789	123456789	123456789	123456789
	Written data	Poster		123456789	123456789	123456789 **PE2.3 (subcompetences 12345)**
	Written data	Concept map, mind map	1234567	1234567	1234567	1234567
	Written data	Report (lab report, excursion report)	123456789	123456789	123456789	
	Written data	Notebook, lab journal	123456789	123456789	123456789	
	Written data	Portfolio		123456789	123456789	
	Performance-based data	Observation of performance / video	1256 **PE2.1**	1256 **PE2.2**	1256 **PE2.2**	
	Performance-based data	Student protocol		123456789	123456789	123456789
	Performance-based data	Artefacts (constructed device, …)	1256	1256	1256	1256
	Oral data	Oral presentation		123456789 **PE2.4**	123456789 **PE2.5**	123456789
	Oral data	Debate, discourse, role-play	123456789	123456789	123456789	123456789
	Oral data	Assessment dialogue		123456789	123456789	123456789
	Oral data	Interview, accountable talk		123456789	123456789	123456789
	Oral data	Audio tapes / video tapes		123456789	123456789	123456789
	Electronically collected data	…	Compare to chapters 5.4 and 7			
	Electronically collected data	…				
	Electronically collected data	…				
	Electronically collected data	…				

Key for the subcompetences:

1) describing and understanding mathematical or ‚real world‘ problems,
2) transferring problems into the ‚mathematical world‘ (if necessary),
3) exploring problems and making conjectures,
4) identifying what is known and what is unknown.
5) creating, using and manipulating mathematical representations,
6) planning and carrying out a problem solving strategy.
7) making and analyzing connections,
8) evaluating the strategy, the conjectures and the meaningfulness of the results,
9) generalizing and systematizing the results and the specific problem solving strategy.

Table 12. Feedback methods and means of data collection put in relation for the 'problem solving in Mathematics' competence (the later adapted from Bernholt et al., 2013). Combinations that might be commonly used in daily teaching are marked blue. Bold numbers indicate that this combination of sub-competence, means of data collection and feedback method is illustrated by a paradigmatic example PE.

A.3 Sub-competence - data collection about student learning - assessment method combinations for "engineering design in technology"

Means of data collection about student learning			Feedback methods: On-the-fly	Marking (grading and written comments)	Self- and peer-assessment	Open classroom discussion and structured classroom dialogue
	Written data	Multiple Choice	**12**		**12**	**128**
		Written answer to open question	**123458**	**123458**	**123458**	**123458**
		Sketch				
		Poster	**123458**	**123458**	**123458**	**123458**
		Concept map, mind map	**125**	**125**	**125**	**125**
		Report (lab report, excursion report)	**1235**	**123578**	**123578**	
		Notebook, lab journal		**12345789**	**123456789**	
		Portfolio		**12345789**	**12345789**	
	Performance-based data	Observation of performance / video				
		Student protocol	**123456789**	**123456789**	**123456789**	**123456789**
		Artefacts (constructed device, …)	**123456789**	**123456789**	**123456789**	**123456789**
	Oral data	Oral presentation	**123457**	**123456789**	**123456789**	**12345678**
		Debate, discourse, role-play	**134**	**1347**	**1347**	**134**
		Assessment dialogue	**1**	**13**	**13**	
		Interview, accountable talk	**14**	**14**	**14**	
		Audio tapes / video tapes				
	Electronically collected data	…	**Compare to chapters 5.4 and 7**			
		…				
		…				
		…				

Key for the subcompetences:

1) defining and delimiting a problem, need or desire,
2) identifying constraints and criteria,
3) investigating relevant information,
4) generating and evaluating possible solutions, analyzing alternatives, selecting a potential solution, justifying the decision.
5) planning design of prototype,
6) constructing prototype (using suitable tools/materials),
7) testing prototype by collecting, analyzing, interpreting and representing data,
8) evaluating prototype against the criteria, reasoning,
9) modifying the design and redesigning if necessary.

Table 13. Feedback methods and means of data collection put in relation for the 'engineering design in Technology' competence (the later adapted from Bernholt et al., 2013). Combinations that might be commonly used in daily teaching are marked blue. Bold numbers indicate that this combination of sub-competence, means of data collection and feedback method is illustrated by a paradigmatic example PE.

A.4 Exemplary learning progressions

Sub-competences	**Exemplary basic standards for grade 4 science students**	**Exemplary basic standards for grade 6 science students**	**Exemplary basic standard for grade 9 science students**	**Exemplary basic standard for grade 12 science students**
Identify questions or diagnose problems	Guided by the teacher, students are able to perceive, observe, and describe simple situations and phenomena with several senses. They can raise simple questions based on the aforementioned actions.	Students are able to perceive, observe, and describe simple situations and phenomena with several senses. They can raise questions based on the aforementioned actions.	Students are able to perceive, observe, and describe *situations and phenomena* with several senses. They can *formulate diversified questions* based on the aforementioned actions.	Students are able to perceive situations and phenomena with several senses, observe them *precisely,* and describe them *using adequate terminology*. They can formulate diversified questions based on the aforementioned actions.
Search for information	Students can, guided by the teacher, search and collect information in relation to a specific question or topic from a given, appropriately edited selection of media. They can compile these pieces of information guided by the teacher. They can distinguish and read, guided by the teacher, different forms of data presentation such as simple tables or diagrams.	Students can, guided by the teacher, search and collect information in relation to a specific question or topic from a *given selection* of media. They can *process* these pieces of information guided by the teacher. They can distinguish and *read* different forms of data presentation such as simple *graphs,* tables, or diagrams.	Students *can search and collect* information in relation to a specific question or topic from a given selection of media. They can process these pieces of information *partly* guided by the teacher. They can distinguish and read different forms of data presentation such as *graphs, tables, or diagrams*.	Students can search and collect information in relation *to a specific question or topic*. They *can process* these pieces of information. They can distinguish and read different forms of data presentation such as graphs, tables, or diagrams *as well as graphical representations of processes or relationships such as flowcharts or concept maps.*
Formulate hypotheses and make predictions	Students can raise guesses based on observations and descriptions of simple situations and phenomena related to their everyday life.	Students can raise guesses based on observations and descriptions of simple *situations and phenomena.*	Students can *formulate simple hypotheses* based on observations and descriptions of *situations and phenomena.*	Students can formulate *hypotheses* based on observations and descriptions of situations and phenomena.

Plan and carry out investigations	Students can apply given tools, instruments, and materials when exploring, examining, and experimenting. Guided by the teacher, they can identify variables from a given selection that are of interest in the context of the investigable question and plan their manipulation. Students can conduct guided investigations and guided experiments. When doing this, they are able to make simple estimates of results, to take measurements in certain situations, to collect, to organise, and to visualize data (e.g., with a simple chart).	Students can *select* and apply suitable tools, instruments, and materials *from a given selection* when exploring, examining, and experimenting. They *can identify* variables from a given selection that are of interest in the context of the investigable question and plan their manipulation. Students can conduct guided investigations and guided experiments. When doing this, they are able to make *estimates* of results, to take *measurements*, to collect, to organise, and to *plot* data.	Students can select and apply *suitable tools, instruments, and materials* when exploring, examining, and experimenting. *They can identify variables* that are of interest in the context of the investigable question and plan their manipulation. Students can conduct guided investigations and guided experiments. When doing this, they are able to form *founded estimates of results*, to *systematically* take measurements, to collect, to organise, and to *appropriately* plot data (e.g. in a table, a graph).	Students can *systematically* select and apply suitable tools, instruments, and materials when exploring, examining, and experimenting. They can identify variables that are of interest in the context of the investigable question and plan their manipulation. *When doing so, they consider aspects of safety and care autonomously.* Students can conduct investigations and experiments *with a certain degree of independence*. When doing this, they are able to form founded estimates of results, to systematically take measurements, to collect, to organise, and to appropriately plot data (e.g. in a table, a graph).
Analyze, interpret, and evaluate data	Guided by the teacher, students can analyze, interpret, and evaluate data. Guided by the teacher, students can identify simple sources of uncertainty in an experimental design, in their observations, in the process of investigating.	Students can analyze, interpret, and evaluate data. Students *can identify* simple sources of uncertainty in an experimental design, in their observations, in the process of investigating.	Students can analyze, interpret, and evaluate data. Students are able to relate the results of the investigations to the hypotheses. Students can identify *sources of uncertainty* in an experimental design, in their observations, in the process of investigating.	Students can analyze, interpret, and evaluate data. Students are able to *critically reflect* on questions and hypotheses based on the results of the investigations. Students can identify sources of uncertainty in an experimental design, in their observations, in the process of investigating and *estimate the influence of these uncertainties on the quality of collected data*.
Develop explanations	Guided by the teacher, students can identify simple structures and patterns in a restricted amount of data and can formulate their findings as general rules in everyday-language.	Students *can identify* simple structures and patterns in a restricted amount of data and can formulate their findings as general rules in everyday-language.	Students can identify *structures and patterns* in a restricted amount of data and can formulate their findings as general rules *using subject-specific vocabulary to an appropriate degree*.	Students can identify structures and patterns in data of appropriate volume and can formulate their findings as general rules *using subject-specific vocabulary. They consider alternative interpretations of the data as well as possible limits of the range of application of the general rules.*

Construct and use models	Compare to chapter 8.6			
Engage in argumentation from evidence	Students can explain what they know of and think on a specific issue related to their everyday life. They can justify their opinion based on their own experiences and partly based on facts ("it is like that, because …"; "it is correct and im-portant, because …..").	Students can explain what they know of and think on a specific issue. They can justify their opinion based on facts / issue-relatedly ("it is like that, because …"; "it is correct and important, because …..").	Students can explain what they know of and think on a specific issue. They can justify their evaluation based on facts / issue-relatedly ("it is like that, because …"; "it is correct and im-portant, because ….."). Students can distinguish their valuation from other arguments and positions.	Students can explain what they know of and think on a specific issue. They can justify their evaluation based on facts / issue-relatedly ("it is like that, because …"; "it is correct and im-portant, because ….."). Students can distinguish their valuation from other arguments and positions based on scientific arguments.
Communicate one's actions by using adequate vocabulary / representations at every stage of the process	Students can describe phenomena as well as results from investiga-tions in science in eve-ryday- language. Guided by the teacher, they can present the aforementioned phe-nomena, situations, needs, and results with appropriate display formats.	Students can describe phenomena as well as results from investiga-tions in science in eve-ryday- language. They can present the aforementioned phe-nomena, situations, needs, and results with appropriate display formats.	Students can describe phenomena as well as results from investiga-tions in science *with a limited range of domain-specific terms, with symbols, and with units.* They can present the aforementioned phe-nomena, situations, needs, and results with appropriate display formats.	Students can describe phenomena as well as results from investiga-tions in science *in do-main-specific terms, with symbols, and with units. Doing this, they can distinguish between everyday-language and scientific language.* They can present the afore-mentioned phenomena, situations, needs, and results with appropriate display formats.

Table 14. Exemplary learning progressions for investigation competence in science education (based on EDK, 2011; Beerenwinkel & Labudde, 2011). It should be mentioned here that a typical problem solving process will probably not be as linear as implicated in these learning progressions.

Sub-competences	Exemplary basic standards for grade 4 mathematics students	Exemplary basic standards for grade 6 mathematics students	Exemplary basic standard for grade 9 mathematics students	Exemplary basic standard for grade 12 mathematics students
Describe and understand a mathematical or 'real world' problem	Students are able to describe simple 'real world' problems.	Students are able to describe simple 'real world' *and simple mathematical problems*.	Students are able to describe *'real world' and mathematical problems containing relational propositions or assignment propositions*.	Students are able to describe 'real world' and mathematical problems containing relational propositions or assignment propositions.
Transfer problems into the 'mathematical world' (if necessary)	Guided by the teacher, students are able to transfer simple 'real world' problems into an arithmetic language.	Students are able to *transfer* simple 'real world' problems into an arithmetic language.	Students are able to transfer *'real world' problems* into an arithmetic language.	Students are able to transfer 'real world' problems into an arithmetic language.
Explore problems and make conjectures	Students can raise guesses based on simple mathematical or 'real world' problems.	Students can raise guesses based on *mathematical or 'real world' problems*.	Students can *make simple conjectures* based on mathematical or 'real world' problems.	Students can *make conjectures* based on mathematical or 'real world' problems.
Identify what is known and what is unknown	Students are able to specify what is given and what is asked in the context of a simple mathematical problem.	Students are able to specify what is given and what is asked in the context of a *mathematical problem*.	Students are able to specify what is given and what is asked in the context of a mathematical problem *containing relational propositions or assignment propositions*.	Students are able to specifying what is given and what is asked in the context of a mathematical problem containing relational propositions or assignment propositions.
Create, use and manipulate mathematical representations	Students are able to represent simple mathematical problems in a specified mathematical representation such as a table, a graph, a symbol.	Students are able to represent simple mathematical problems in a specified mathematical representation such as a table, a graph, a symbol.	Students are able to represent *mathematical problems containing relational propositions or assignment propositions* in a given mathematical representation such as a table, a graph, a symbol.	Students are able to represent mathematical problems containing relational propositions or assignment propositions in a *suitable* mathematical representation such as a table, a graph, a symbol.
Plan and carry out a problem solving strategy	Guided by the teacher, students can plan and carry out a problem solving strategy for mathematical problems that are solvable in few steps by breaking down the problem into a number of smaller steps and by applying a given algorithm to each part of the problem. Typical solving strategies include the search for analogies or systematic variation.	Students can plan and *execute* a problem solving strategy for mathematical problems that are solvable in few steps by breaking down the problem into a number of smaller steps and selecting an algorithm from a small selection for each part of the problem. Typical solving strategies include the search for analogies and to start the problem solving process backwards.	Students can plan and *conduct* a problem solving strategy *for mathematical problems* by breaking down the problem into a number of smaller steps and *choosing* an algorithm for each part of the problem. Typical solving strategies include the search for analogies and to start the problem solving process backwards.	Students can plan and conduct a problem solving strategy for *complex* mathematical problems by breaking down the problem into a number of smaller steps and choosing an algorithm for each part of the problem. Typical solving strategies include the search for analogies and to start the problem solving process backwards.
Make and analyze connections	Guided by the teacher, students can recognize and describe simple connections and similarities between a limited	Students can recognize and describe simple connections and similarities between a limited number of different	Students can recognize and describe connections and similarities between a number of different mathematical	Students can recognize and describe connections and similarities between different math-

	number of different mathematical problems.	mathematical problems.	problems.	ematical problems.
Evaluate the strategy, the conjectures and the meaningfulness of the results	Students can decide if the mathematical result is meaningful in the context of the mathematical problem.	Students can decide if the mathematical result is meaningful in the context of the mathematical problem.	Students can *critically reflect on the solving strategy chosen, on mistakes made in the solving process and* decide if the mathematical result is meaningful in the context of the mathematical problem.	Students can critically reflect on the solving strategy chosen, on mistakes made in the solving process and decide if the mathematical result is meaningful in the context of the mathematical problem *and identify the need for additional information or clarification.*
Generalize and systematize the results and the specific problem solving strategy	Students can describe their solving approach of a mathematical problem in their own words.	Students can describe their solving approach of a mathematical problem in an *appropriate degree of abstraction* using everyday-language.	Students can *formulate a generalised function of a specific solving approach or of specific structures and patterns*.	Students can formulate a generalised function of a specific solving approach or of specific structures and patterns. *They consider possible limits of the range of application of the generalised function.*
Communicate one's actions by using adequate vocabulary / representations at every stage of the process	Students can describe solving strategies in Mathematics in everyday- language. Guided by the teacher, they can present the aforementioned phenomena, situations, needs, and results with appropriate display formats.	Students can describe solving strategies in Mathematics in everyday- language. They can present the aforementioned phenomena, situations, needs, and results with appropriate display formats.	Students can describe solving strategies in Mathematics *with a limited range of domain-specific terms, with symbols, and with units.* They can present the aforementioned phenomena, situations, needs, and results with appropriate display formats.	Students can describe solving strategies in Mathematics *in domain-specific terms, with symbols, and with units. Doing this, they can distinguish between everyday-language and scientific language.* They can present the aforementioned phenomena, situations, needs, and results with appropriate display formats.

Table 15. Exemplary learning progressions for problem solving competence in Mathematics education (based on OECD, 2013; Muijs & Reynolds, 2011; EDK, 2011; OECD, 2013). It should be mentioned here that a typical problem solving process will probably not be as linear as implicated in these learning progressions.

Sub-competences	Exemplary basic standards for grade 4 technology students	Exemplary basic standards for grade 6 technology students	Exemplary basic standard for grade 9 technology students	Exemplary basic standard for grade 12 technology students
Define a problem / need and ask question	Students are able to perceive and describe simple problems, needs, or desires in a familiar context that suggest an engineering problem that needs to be solved. They can raise simple questions and guesses based on the aforementioned acts.	Students are able to perceive and describe *simple problems, needs, or desires* that suggest an engineering problem that needs to be solved. They can raise questions and guesses based on the aforementioned acts.	Students are able to realise and describe *problems, needs, or desires* that suggest an engineering problem that needs to be solved. They can *formulate diversified questions* based on the aforementioned acts.	Students are able to realise problems, needs, or desires that suggest an engineering problem that needs to be solved and describe them *using adequate terminology*. They can formulate diversified questions based on the aforementioned acts.
Identify constrains and criteria	Guided by the teacher, students can identify constrains and criteria from a given selection that are of interest in the context of the problem / need.	Students *can identify* variables from a given selection that are of interest in the context of the problem / need.	*Students can identify variables* that are of interest in the context of the problem / need.	Students can identify variables that are of interest in the context of the problem / need. *When doing so, they consider aspects of safety and care autonomously.*
Investigate relevant information	Students can, guided by the teacher, search and collect information in relation to a specific question or topic from a given, appropriately edited selection of media. They can compile these pieces of information guided by the teacher. They can distinguish and read, guided by the teacher, different forms of data presentation such as simple tables or diagrams.	Students can, guided by the teacher, search and collect information in relation to a specific question or topic from a *given selection* of media. They can *process* these pieces of information guided by the teacher. They can distinguish and *read* different forms of data presentation such as simple *graphs,* tables, or diagrams.	Students *can search and collect* information in relation to a specific question or topic from a given selection of media. They can process these pieces of information *partly* guided by the teacher. They can distinguish and read different forms of data presentation such as *graphs, tables, or diagrams*.	Students can search and collect information in relation *to a specific question or topic*. They *can process* these pieces of information. They can distinguish and read different forms of data presentation such as graphs, tables, or diagrams *as well as graphical representations of processes or relationships such as flowcharts or concept maps.*
Generate and evaluate possible solutions, analyze alternatives, select a potential solution, justify the decision	Guided by the teacher, students can evaluate possible solutions from a given selection that are of interest in the context of the problem / need, select a potential solution and give a reason for the decision.	Students can *evaluate* possible solutions from a given selection that are of interest in the context of the problem / need, select a potential solution and give a reason for the decision.	Students can *generate and evaluate* possible solutions that are of interest in the context of the problem / need, select a potential solution and *justify the decision.*	Students can generate and evaluate possible solutions that are of interest in the context of the problem / need, select a potential solution and *justify the decision in detail based on the analysis of the alternatives*.
Plan the design of a prototype	Guided by the teacher, students can plan the design of a prototype.	Guided by the teacher, students can plan the design of a prototype.	Students can *plan* the design of a prototype.	Students can plan the design of a prototype.
Construct a prototype	Students can conduct guided construction work. Students can apply suitable tools, instruments, and materials	Students can conduct guided construction work. Students can *select* and apply suitable tools, instruments, and materi-	Students can conduct guided construction work. Students can select and apply suitable tools, instruments, and materi-	Students can conduct construction work *with a certain degree of independence*. Students can *directedly* select and apply suitable

	when constructing a prototype.	als from a given selection when constructing a prototype.	als when constructing a prototype.	tools, instruments, and materials when constructing a prototype. *They consider aspects of safety and care autonomously.*
Test prototype by collecting, analysing, interpreting and representing data	Students are able to form simple estimates, take measurements in certain situations, collect and organize data (e.g., chart, table) to help them identify how effective, efficient, and durable their designs may be under a range of conditions.follow]	Students are able to form *estimates*, take *measurements*, collect and organize data (e.g., chart, table, *diagram, plot*) to help them identify how effective, efficient, and durable their designs may be under a range of conditions.	Students are able to form *founded* estimates, *systematically* take measurements, collect and plot data; e.g. in a table, a graph to help them identify how effective, efficient, and durable their designs may be under a range of conditions.	Students are able to form founded estimates, systematically take measurements, collect and plot data e.g. in a table, a graph (to help them identify how effective, efficient, and durable their designs may be under a range of conditions).
Evaluate prototype against the criteria, reason, modify the design and redesign if necessary	Guided by the teacher, students can identify the range of good solutions on a specific problem from a small variety of different solutions. Guided by the teacher, they can perform simple modifications of an individual design based on the identification of the range of good solutions.	Students *can identify* the range of good solutions on a specific problem from a small variety of different solutions. They *can perform* simple modifications of an individual design based on the identification of the range of good solutions.	Students can identify the range of good solutions on a specific problem from a *given* variety of different solutions, products or prototypes. They *can justify, plan* and perform *modifications* of an individual design based on the identification of the range of good solutions, products or prototypes.	Students can identify the range of good solutions on a specific, *complex* problem from a given variety of different solutions, products or prototypes. They can justify, plan and perform modifications on an individual design based on the identification of the range of good solutions, products or prototypes.
Communicate at all stages of the process	Students can describe problems, needs and desires as well as results from testing prototypes in Technology in everyday- language. Guided by the teacher, they can present the aforementioned phenomena, situations, needs, and results with appropriate display formats.	Students can describe problems, needs and desires as well as results from testing prototypes in Technology in everyday- language. They can present the aforementioned phenomena, situations, needs, and results with appropriate display formats.	Students can describe problems, needs and desires as well as results from testing prototypes in Technology *with a limited range of domain-specific terms, with symbols, and with units.* They can present the aforementioned phenomena, situations, needs, and results with appropriate display formats.	Students can describe problems, needs and desires as well as results testing prototypes in Technology *in domain-specific terms, with symbols, and with units. Doing this, they can distinguish between everyday-language and scientific language.* They can present the aforementioned phenomena, situations, needs, and results with appropriate display formats.

Table 16. Learning progressions for engineering design in Technology education. Based on EDK, 2011; Beerenwinkel & Labudde, 2011 and National Research Council, 2012.

	Sub-competences	Grades 1-6	Grades 7-9	Grades 10-12
Argumentation Practices	**Constructing Arguments**	Students can: State a claim (opinion or conclusion) and a counter-claim and justifying them with scientific evidence or personal beliefs	Students can: State a claim (opinion or conclusion) and a counter-claim and justifying them with ***scientific evidence (grounds/reasons/justifications)*** ***Construct integrated arguments using claim and grounds/reasons/justifications***	Students can: State a claim (opinion or conclusion) and a counter-claim and justifying them with scientific evidence (grounds/reasons/justifications) Construct integrated arguments using claim, grounds/reasons/justifications *and* ***rebuttals***[1]
	Analyzing Arguments	Students can: Analyze arguments into constituent components (structural elements) (claim, evidence)	Students can: ***Analyze grounds into data, warrant, backing*** Analyze arguments into constituent components (structural elements) (claim, ***data, warrant, backing***) ***Identify the elements of dialogic argumentation (argument, counter-argument and rebuttal[2])***	Students can: Analyze grounds into data, warrant, backing Analyze arguments into constituent components (structural elements) (claim, data, warrant, backing*,* ***rebuttal***) Identify the elements of dialogic argumentation (argument, counter-argument, and rebuttal) ***Identify different types of counter-argument to counter-alternative and counter-critique***
	Communicating Arguments	Students can: Discuss a topic Listen carefully their peers	Students can: Discuss a topic Listen carefully their peers ***Deal with data depending on the target audience***	Students can: Discuss a topic Listen carefully their peers Deal with data depending on the target audience ***Construct arguments depending on the target audience using appropriate evidence and language*** ***Debate***
Meta-Knowledge	**Metacognitive knowing**	Students know: The role and importance of each specific constituent component of an argument (claim, evidence)	Students know: The role and importance of each specific constituent component of an argument (claim, ***data, warrant, backing***) **The role and importance of**	Students know: The role and importance of each specific constituent component of an argument (claim, data, warrant, backing, ***rebuttal***) The role and importance of dialogic argumentation ele-

[1] Rebuttal is the condition under which the claim cannot hold and consequently it limits the claim and prevents possible counter-arguments, in individual argumentation (Toulmin, 1958)

[2] Rebuttal can integrate an argument by criticizing the counter-argument, in dialogic argumentation (Kuhn, 1991)

			dialogic argumentation ele-ments (argument, counter-argument, rebuttal)	ments (argument, counter-argument, rebuttal) ***The role and importance of different types of counter-arguments (counter-critique and counter-alternative)***
	Metastrategic knowing	Students know: The meaning to be a part of a discussion as listener or as argu-er/discussant The importance of engaging in an everyday discussion	Students know: The meaning to be a part of a discussion as listener or as arguer/discussant The importance of engaging in a ***structured*** discussion	Students know: The meaning to be a part of a discussion as listener or as arguer/discussant The importance of engaging in a discussion ***How to implement the dialogic argumentation elements***
	Epistemologi-cal knowing		Students can: Differentiate between the scientific data and personal beliefs Differentiate between the primary and secondary data sources	Students can: Differentiate between the scien-tific data and personal beliefs Differentiate between the prima-ry and secondary data sources ***Recognize that the argument should be acceptable to the arguer or the audience to which the argument is di-rected***

Table 17. Learning progressions for argumentation. Written by Demetris Koursaris, Elena Siakidou, Nikos Papadouris, Costas Constantinou.

	Sufficient	Better	Good
Creativity competence			
Generating ideas	The student accounts for given ideas (for problems or issues in relations to the professional area and theme, or for solutions related to the given problems).	The student formulates and accounts for ideas (for problems or issues in relations to the professional area and theme, or for solutions related to the given problems).	The student develops (for problems or issues in relations to the professional area and theme, or for solutions related to the given problems).
Working with ideas in a critical fashion	The student explains the difference between different solutions/problems.	The student compares solutions/problems in relation to their relevance/realizability.	The student further develops and elaborates solutions/problems to increase their relevance.
Collaboration competence			
Responsibility in group work	The student follows others' planning and coordination, and takes on a role in the group.	The student coordinates his/her own working process in the cooperation by for example taking on different roles throughout the group work.	The student coordinates the group's working process and decides the situations in which he/she has to take on a certain role in the group.
Flexibility in group work	The student contributes to the group work with his/her own competencies.	The student invites others to make use of their competencies.	The student actively uses others' competencies in the working process.
Navigation competence			
Decoding and application	The student identifies the professional area that the problem relates to.	The student uses some professional terms to work with the problem.	The student combines professional terms and uses terminology as he/she works with the problem.
Managing knowledge	The student gives an account of knowledge and information relevant to the work with the problem.	The student compares different pieces of information according to their relevance to the work with the problem.	The student decides and states the reasons for what knowledge and pieces of information is most relevant to draw on, according to the work with the problem.
Action/Implementation competence			
Acting on missing knowledge	The student obtains knowledge from previously used material.	The student picks up knowledge in (to the student) new relevant material.	The student produces (for the student) new knowledge by looking up different sources.
Carrying out actions	The student commences the execution of the planned work.	The student commences and keeps up the execution of the planned work.	The student commences, keeps up on, and finishes up the execution of the planned work.
Qualification of actions	The student distinguishes between the different actions.	The student compares potential actions with reference to an identification of their consequences.	The student justifies what actions need to be carried out on the basis of an impact assessment.
Communication competence			
Communication analysis	The student uses presentation techniques that make the presentation of the problem/solution easy to understand.	The student plans his/her presentation of the problem/the solution under consideration of target group, language and topic.	The student justifies his/her choice of presentation form and technique according to target group, language and topic.
Communication practices	The student presents in a way that is comprehensible.	The student presents clearly and somewhat convincingly.	The student presents clearly and convincingly with a large degree of commitment.

Table 18. Learning progressions for innovation, upper secondary level. Written by Jan Alexis Nielsen.