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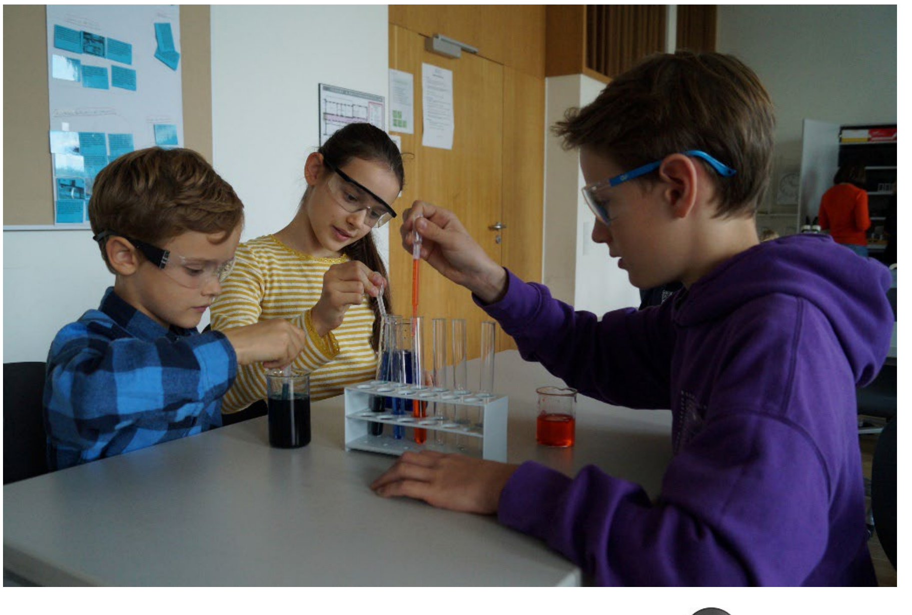
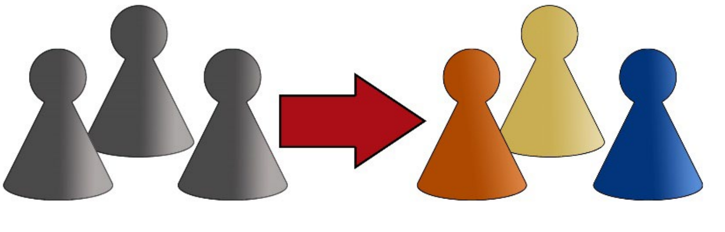
Differentiation in Inquiry-based Learning

A Differentiation Tool with a Focus on Experimentation





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Differentiation in Inquiry-based Learning
A Differentiation Tool with a Focus on Experimentation

Edited by:

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1 Introduction

Application of internal differentiation in the classroom has become a topic of importance for all school subjects (Heymann, 2010). "Internal differentiation" means that learners[1] in a class are divided into learning groups and supplied with different learning material or learning strategies, so that learning success can be ensured for all. These groups can be homogeneous groups – high-performing groups, low-performing groups and groups in between – or heterogeneous groups. In heterogeneous groups, the learners in each group can support each other according to their strengths. There are different concepts of internal differentiation to address different learners' interests, prior knowledge, cognitive stage of development, or skills. Concepts of differentiation to support individual achievement – performance differentiation – exist primarily for content-based competencies and mathematical competence, in addition to reading and writing (cf. Tomlinson & Moon, 2013). Differentiation in science subjects (biology, chemistry, and physics) regarding procedural competencies has not yet been developed. However, the significance of procedural competencies in science subjects is also uncontested (Bybee, 2002; Hodson, 2014). The expert report to the European Commission titled "Science Education for Responsible Citizenship" (Hazelkorn et al., 2015) recommends a stronger practice of inquiry-based approaches in science education. Inquiry-based learning is one such inquiry-based approach. The connection between procedural competencies and inquiry-based learning is that, in inquiry-based learning, learners build up new knowledge themselves through their own investigations. It is important to consider that, in our opinion, the implementation of inquiry-based learning cannot take place without having learners learn, perform, and practice the methods of scientific inquiry. Experimentation takes a prominent place in the methods of scientific inquiry (Baur & Emden, 2020; Emden & Baur, 2017; Schwichow et al., 2016). To cover all methods of scientific inquiry in one book does not seem to us to be expedient, because one would not do justice to the different scientific inquiry methods. So, this book focuses on experimentation as the widely used method in inquiry-based learning and the performance differentiation of procedural competencies of experimentation. Procedural competencies in scientific inquiry with experimentation include, for example: competencies to state a question, generate a hypothesis, plan an experiment, perform an experiment, and draw conclusions (Mayer et al., 2008; Schmidt, 2016).

[1] The focus in this book is on differentiation tailored to school-age learners, although much of it may also apply to older people in learning situation. For the sake of clarity and consistency, we use "learners" throughout to designate both "pupils" and "students".

In our opinion, learning procedural competencies can be supported with differentiation and scaffolding tailored to learners' skills. Scaffolding is a process in which learners use aids, hints, prompts, and so on, without which learners could not solve the tasks they are given to work on. Scaffolding is a dynamic process in which support is offered to learners according to their current abilities until they reach autonomous performance of the supported task (Pea, 2004). Scaffolding could be seen as an aid to help learners to reach the next level. In addition to scaffolding, differentiation is crucial. Differentiation offers learners a personalized learning environment (choosing a level that each learner can cope with). This environment fosters the performance of certain skills but, at the same time, remains challenging for learners. So, learners should work with experimentation tasks that involve different levels of openness. Learners' work with completely open experimental tasks is an educational objective in science subjects, but learners must first learn to experiment openly; they need an adaptive learning environment for this learning process. Furthermore, differentiation in the formulation of tasks and in the presentation of the problem to be solved with an experiment proves beneficial. Diagnostics and feedback are necessary to facilitate learners' learning processes (Ingenkamp & Lissmann, 2008). Hence, the development of differentiation concepts (for performance differentiation) requires thorough knowledge of learners' misconceptions, errors, and difficulties (whereby errors are perceived as a learning opportunity rather than a deficit), knowledge about diagnostic and feedback possibilities and, of course, knowledge about differentiation and scaffolding in the domain itself (in this project, the domains are biology, chemistry, and physics). The respective project partners of this Erasmus+ project "Differentiation in Inquiry-based Learning with a Focus on Experimentation" (acronym DifferentiatInq) brought together this expertise in inquiry-based learning, formative assessment, pedagogical diagnosis, scaffolding, differentiation, learners' errors, and learners' misconceptions to develop a concept for teaching practice in the field of experimentation (the Differentiation Tool). This concept was adapted to school needs through prior interviews with teachers, a review process by three external experts and subsequent exchange with teachers from the project partner schools. The external experts were Prof. Dr. Markus Emden (University of Education Zurich, Switzerland – chemistry education), Prof. Dr. Manuela Welzel-Breuer (University of Education Heidelberg, Germany – physics education), and Prof. Dr. Marcus Hammann (University Münster, Germany – biology education).

The feedback we received from teachers via the interviews we conducted showed us that a detailed presentation and explanation of inquiry-based learning and experimentation was crucial for the purpose of this book. So, we included Chapter 3, "Inquiry-based learning" and Chapter 4, "Experiments and how to use them for inquiry-based learning". Both chapters offer definitions and further explanations. As differentiation and scaffolding are essential parts of the topic of this book, Chapter 2, “Differentiation and scaffolding”, introduces the two concepts and offers theoretical considerations and practical issues about differentiation in science teaching. Chapter 5, “Assessment for inquiry-based learning” describes different goals and methods for assessing learners’ inquiry competencies. In Chapter 6, “The Differentiation Tool for inquiry-based learning”, differentiation and scaffolding are combined with inquiry-based learning and, especially, experimentation. The Differentiation Tool offers a framework with five levels of decision-making to create individual learning environments (a decision to select the domain of knowledge and four decisions to design the differentiation). The decisions must be made to design an individual learning environment and learning process. Chapter 7, “Teaching examples: application of the Differentiation Tool”, consists of various examples for implementation in teaching. Finally, Chapter 8, “Safety regulations in a laboratory and for experimental work” provides guidance on security aspects of experimentation.

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2 Differentiation and scaffolding

Differentiation – the adaptation of teaching to individual differences – is crucial for academic and non-academic school outcomes (Westwood, 2001). There are different ways of responding to learner diversity. The first possibility of differentiation here is "external differentiation", which separates children and young people with similar achievements, interests or competencies in terms of school organization. In Germany and Austria this usually happens after elementary school, in Finland and Cyprus later (more in Example 2.2.). If we are already at the instructional level, we speak of "internal differentiation" when we apply differentiation in class. Internal differentiation addresses learner differences and seeks to find suitable approaches in the respective setting. As explained later, differentiation can be applied in homogenous groups, in heterogeneous groups, and in individual work. In the following, we will go into more detail about the possibilities of internal differentiation at the teaching level and refer to it by the term "differentiation".

Although differentiation is important for learning, it is not used as often in teaching as it should be (Tomlinson, 2014). The interviews we conducted with 30 teachers revealed some reasons: some of our interviewed teachers did not perceive their classes as being heterogeneous enough; the concept of differentiation and how to use it in class were not clear; the teachers did not have enough information about how to handle differentiation; differentiation was imagined to be rather complex and time-consuming; circumstances in school were not seen as supporting differentiated teaching and learning. On the other hand, teachers valued heterogeneity of learners in class as it enabled different perspectives and approaches – for example, learning at one's own pace and learning together from each other. Social competence can also be promoted in this way (interviews in preparation for this book with teachers from Cyprus, Austria, Finland, and Germany; conducted in 2019; *N* = 30).

There are many good reasons why differentiation may not be used in school. But there are also many reasons why the use of differentiation is absolutely necessary and worthwhile. In our opinion, differentiation does not necessarily mean more work for teachers. This chapter first provides arguments for differentiated science teaching. Later, possibilities for dealing with differentiation in class are introduced. Special attention is given to the topic of "scaffolding" – an effective possibility for teachers to react to learners' needs and to guide them to the next level of development (Schnotz, 2006). In scaffolding, learners are offered support in the form of an "auxiliary scaffolding" so that they can master the task to be worked on independently. Scaffolding can be seen as a form of help so that learners can take the next, harder step. Through differentiation, learners are offered a tailor-made learning environment. Differentiation and scaffolding overlap and cannot always be distinguished from each other.

2.1 Heterogeneity in classroom settings

Example 2.1

Lucy, 13 years old, is an attentive learner. She has huge prior knowledge but she has problems with organizing her work. Tom, 12, is really interested in natural sciences and math. He has problems with reading comprehension and writing. Ali, 13, is new in class. The focus of his former science teacher was reproducing knowledge. They did not work in cooperative or open settings.

Ms. Smith is in her third year as a science teacher in secondary school. The class consists of 26 learners with various social and cultural backgrounds. Besides these differences, there is huge variety in how the learners do their work. Learning paths, preconditions, and prior knowledge are just a few of them. Ms. Smith is planning an inquiry-based learning session with a focus on unicellular organisms. So what does she have to consider? Is it necessary that every learner achieves the same goal? If so, how can the teacher support the learning processes?

Example 2.1 shows that classes are not homogenous groups. Learners are individuals who differ in various aspects – some of these aspects are tightly connected to subject learning, like prior knowledge or interest in the subject. Others affect learning in all subjects, like reading competencies, digital competencies, or fundamental mathematical competencies, as well as metacognitive skills or skills in self-organization. Although learners are individuals who differ in various ways, there may be some aspects they share. For example, learners in a natural-sciences class may be connected by their interest in scientific topics and methods.

The terms “heterogeneity” and “homogeneity” are in tension with each other. The tension between these two terms is often discussed in pedagogy and it is a real-life problem for active teachers in the classroom (Buholzer & Kummer Wyss, 2010). The term “heterogeneity” – or, as also used synonymously, “diversity”, “plurality”, or “variety” – presents itself as multilayered and complex. There is no real agreement on a definition (Zulliger & Tanner, 2013). In general, it can be concluded that the term means the diversity of learners in one or more attributes (Martschinke, 2015; Scholz, 2012).

There is clear agreement that teachers in classrooms are faced with homogeneity and heterogeneity, and equality and diversity. Before the modern discussion, Herbart (1776-1841) recognized the need to focus on the progress of each learner individually. Learners differ in their personalities, preconditions, skills, talents, and, as a result, in their needs. Nowadays, teachers may even perceive more heterogeneity in their classes due to social and political requirements like the restructuring of school systems (comprehensive and community schools), the desire for inclusive education, or language and culture proficiencies due to migration (Dixon et al., 2014). Paying attention to those differences allows all learners to experience a degree of success while maintaining their differences. By contrast, teaching for the “average” learner by using a single approach for all disregards learners’ capabilities, interests, and learning requirements (Subban, 2006).

Task 2.1

Imagine one class or group of learners you are teaching. What are the aspects the learners in this class have in common? In what aspects do you think the learners differ?

What is your feeling about teaching this special class with all the things they share or in which they differ?

Do the differences affect your teaching? If so, do they impede or facilitate your teaching?

How do you use learners’ similarities and differences in your teaching?

Are you well-prepared for teaching this special group of learners with all their needs?

To adjust teaching to learners’ requirements positively influences learners’ academic achievements (Baumgartner et al., 2003; Firmender et al., 2013; Valiandes, 2015). Learning is more effective when learners are challenged in an appropriate way; they should neither be underchallenged nor overchallenged (Subban, 2006; Tomlinson, 2014). Besides, taking into account learners’ differences enhances their motivation, through giving them the feeling of autonomy and the experience of competence (Deci & Ryan, 2008).

2.2 Differentiation as an answer to heterogeneity

Although the heterogeneity of learners can also be seen positively as an enrichment for learning, it is often perceived as inhibiting learning progress or competency achievement and making teaching more complex. So, various efforts have been undertaken to reduce the complexity for the school system that is caused by heterogeneous learning groups. Often, these efforts are a topic in educational policy. Heterogeneity caused by differences in performance is attenuated by school systems which separate learners according to their performance levels (e.g., comprehensive schools and *Gymnasien* in German-speaking countries). Heterogeneity caused by individual interest is solved by offering key topics for classes or even entire schools (e.g., science classes, sports classes, music classes). Such differentiation efforts are called “external differentiation”, as they try to solve problems caused by heterogeneity outside classroom teaching by separating learners according to their differences to form more homogeneous groups (Scholz, 2012).

Example 2.2

School tracks and selective school systems

In general, countries can be classified according to when they separate learners. Some wait until the end of lower secondary – for example Cyprus, which separates learners at the age of 12, or Finland, which separates learners at 16. Others have selective school systems that force early separations. German-speaking countries, for example Austria and a large part of Germany, separate learners directly after primary school at the age of 10 according to their achievements. The underlying belief is that homogenous classes are easier to educate and their achievements are better than heterogeneous groups because stronger learners can be better challenged and weaker learners can be better supported (Kiel et al., 2015).

The national education report for Austria shows that the separation after primary school leads to a higher similarity of performance than in primary school (Breit et al., 2019). The situation in Germany is similar. However, data from PISA (2001, 2015) nevertheless show overlap between the achievements in the differentiated school system in Germany for mathematics and natural science (Reiss et al., 2016). There is a correlation between early-separating systems and educational injustice. Data show that learners who receive higher-level education after primary school (based on their grades or entrance exams) are often those whose parents have higher education and achieved higher school leaving qualifications, too (Bruneforth et al., 2016).

There is no consensus on the relationship between heterogeneity and achievement. Studies prove that there is no effect from heterogeneity on learners individual progress (a.e. Gröhlich et al., 2009). Appropriately, data from the Austrian national education report also show components of heterogeneity with regard to the social, cultural, and linguistic backgrounds of the learners. In fact, over the years, the percentage of learners who choose higher education after primary school in separating systems has increased (Bruneforth et al., 2016). So, heterogeneity in classrooms is increasing, even in separating school systems.

Despite efforts to create homogenous learning groups, external differentiation only reduces certain aspects of heterogeneity, whereas other aspects are not affected at all. The responsibility to deal with differences in classes in a sensible way therefore lies with teachers.

Teachers react to heterogeneity in different ways. They react in a passive way by ignoring differences, planning and teaching for an average learner. The substitutive way requires the learners themselves to adapt in class. Different learning requirements must be reduced in advance, for example by offering remedial classes for learners with specific difficulties. The goal is that learners with difficulties become able to follow what is going on in class independently. The active forms of teachers' reaction provide support for the whole class or for groups of learners, meaning that the teacher adapts the teaching to the diversity of the learners and provides assistance for different groups of learners. Mostly, the teacher provides aids for different homogeneous groups, but it is also possible to form heterogeneous groups in which learners can also support each other. If learners with heterogeneous abilities are to achieve the same objective, it is up to the teacher to find different ways for variably competent groups. In this case, one also speaks of “convergent diversity”. A second possibility is that learners with similar levels of competence should achieve different objectives. In this case, the goal and the ways to reach it vary. This type of differentiation is also called “divergent” (Deunk et al., 2018).

Proactive instructional opportunities go a step further to help individual learners with different learning objectives (Martschinke, 2015; Weinert, 1997), which will lead to a braoder range of assistance in practical cases, concentrating on individual learners who need help. All efforts for dealing with heterogeneity actively or proactively in teaching are part of internal differentiation.

Internal differentiation contains different methods for learning in classroom settings. In contrast to external differentiation, the whole classes are not separated. But it is indispensable to open up the classroom activities to provide learners with differentiated and adaptive topics and learning material. In self-learning phases, learners can work at their own pace while receiving appropriate support from the teacher. So, the teacher needs special qualifications. These competencies are often summarized under the term “adaptive teaching competencies”. They include professional, technical, psychologico-pedagogical, and didactic competencies as well as attitudes, motives, and self-efficacy expectations (Schiffl et al., 2019).

Internal differentiation is a learning principle that is designed differently (Tomlinson, 2014). It is a collection of different concepts that appreciate learners’ differences in teaching. Common concepts of differentiation in the classroom are “adaptive teaching” (Corno, 2008; Westwood, 2018) or the broader concept of “differentiated instruction” (Pozas et al., 2020; Suprayogi et al., 2017).

For ease of reading, we simply use the term “differentiation” below to mean internal differentiation.

Adaptive teaching is a principle implying the adaptation of teaching to the needs of each individual learner (Corno, 2008). For example, if the class consists of 20 learners, each gets a learning program that fits their individual needs. Adaptive teaching is to be equated with the term “individualization” (*Individualisierung*), which is commonly used in German-speaking countries (Helmke, 2013). To implement this principle, teachers need to apply internal differentiation in classroom settings; they need adaptive teaching competence, meaning the ability to adapt planning and teaching to the individual conditions and capabilities of their learners (Beck et al., 2008). This definition encompasses four fields of competencies which teachers must have (Weinert, 2000). First, teachers require professional and technical competencies regarding the teaching subject. Second, teachers need to have diagnostic competencies, which include the skills to diagnose states of knowledge, possible progress, and learning problems. The third requirement is didactic competency, which includes, among other things, the skill to select appropriate methods for the learning process. Not least, it is important to manage the classroom, which includes the competency to handle trouble and time and design a learner-friendly environment. These fields of competencies are requirements for planning and designing adaptive educational processes.

Differentiated instruction was originally designed to meet the needs of gifted learners but is now used as a method to address individual learning needs and maximize learning outcomes for all learners (Gheyssens et al., 2020). It aims to enable maximal learning for all by giving differentiated instruction (Tomlinson, 2001). In contrast to adaptive teaching, differentiated teaching focuses on an adaptation of the learning object to specific learning groups (Helmke, 2013). So, unlike in adaptive teaching, where every learner gets their own learning program, in differentiated instruction the teacher builds groups with similar skills. Differentiated instruction in class is carried out through differentiation of content, processes (tasks, learning activities), or products (Tomlinson, 2017). Facilitating effects arise from social interaction with peers or from teacher-provided scaffolds – prepared in advance or given spontaneously during teaching (Kress & Pappas, 2016; Müller, 2012, 2018; Tomlinson, 2017).

2.3 Methods of internal differentiation

Let's go back to the interviews we carried out with 30 biology, chemistry, and physics teachers. One question we asked them was about the way they used differentiation in their science teaching. Most of the teachers reported taking into account learners' interests and learners' performance levels.

Teacher A: "I look at learners' performance levels and interests individually."

Teacher B: "I do differentiation according to learners' performance and according to learners' interests."

For gifted learners, differentiation was mostly controlled through extra work or more difficult tasks.

Teacher C: "All learners do the basics first. Learners who are finished fast get new, more difficult tasks."

For learners who needed support, it was given on-the-spot through extra explanations and help from the teacher or by the preparation of supporting material like clue cards.

Teacher D: "I have different handouts for the same experiments with less information for those who have no problems and more for those who do."

Some teachers used special group structures or peer systems for providing help. As far as interest is concerned, most teachers offered different topics up to learner vote.

Teacher B: "For differentiation according to interest: bring out different points of one topic and learners can choose their preferred point."

The sample of interviews was quite small and not representative, but it outlines common methods for differentiation used in science classes. To complete this picture, we collected promising methods from literature.

Differentiation can be carried out with respect to content, tasks and learning activities, resources (for example materials), or learning outcomes. In class, it can be facilitated by the teacher or through peers (Kress & Pappas, 2016; Müller, 2012, 2018). Table 2.1 shows different methods used in differentiation. For more examples of differentiation and scaffolding, see Table 6.2.

Table 2.1: Methods for differentiation (Kerry & Kerry, 1997)

differentiation by context	adapting contexts through complexity
	adapting contexts through quantity
differentiation by tasks and learning activities	asking open questions more often
	asking cognitively challenging questions
	setting tasks with no single correct solution
	settings tasks with increased thinking demand
	using different tasks for different learners
	using different learning activities for different learners or groups of learners
	challenging learners' assumptions
differentiation by outcome	using individual learner objectives
	allowing learners to record responses in different ways
	allowing different products for different learners
	using time for extended projects
	using methods of marking which allow learners to show their best pieces of work (e.g., portfolios)
differentiation by resources	using graduated worksheets
	making additional resource packs available

	preparing clue cards
	using texts with different comprehension difficulty levels

Many methods for differentiation must be planned. In this case, teachers may prepare their lessons with special sequences for internal differentiation, special materials (differentiated texts or worksheets, clue cards, additional material), assignments, or settings (group settings, workstations, individual learning phases, etc.) which foster differentiation. Differentiation in the class context does not mean that tasks and work packages must be designed individually for every learner. This approach would take a lot of time and overstrain teachers' resources. The focus of planned differentiation in class is to provide different offers for groups with similar backgrounds or to anticipate problems which may be common in understanding topics.

But differentiation does not only exist in planned form. Teachers may appreciate (e.g., through feedback or observation) that several learners have problems with study material during teaching. Then, the teacher must react spontaneously to the situation by using "on-the-fly" differentiation (Carolan & Guinn, 2007). Methods for on-the-fly differentiation include adapting speech and explanations; repeating, providing additional information; using more or different examples; and thinking-aloud phases or where the teacher explains what they are thinking and taking into account while carrying out certain methods or making certain decisions. Challenging learners' assumptions by back-questioning is also a differentiation method to develop learners' understanding (Nieminen et al., 2020). Teachers who successfully apply "on-the-fly" differentiation:

- notice learners' problems at an early stage;
- show readiness to react flexibly to new requirements;
- have adequate knowledge to explain contents in different ways;
- have adequate methodological skills to provide supportive learning opportunities.

Which approach of differentiation is chosen – planned or on-the-fly – depends on the teacher's preferences (influenced through beliefs about teaching, teacher training received, and self-efficacy) and experience (Suprayogi et al., 2017). Planned differentiation needs more time in advance but reduces complexity in teaching, as many decisions can be considered in advance. On-the-fly differentiation is less time-consuming but requires special knowledge and skills which need to be applied in the teaching situation directly.

Scaffolding is a successful approach for teachers to foster learners' progress. The next section therefore gives information about the approach of scaffolding and how to use it in teaching. We are fully aware of the importance of scaffolding for differentiation and of the quantity of remarkable research on this topic. But as scaffolding is not the focus of this book, we only consider its main points, which may be of help to science teachers when designing their teaching.

2.4 What is scaffolding?

The term "scaffolding" can be traced back to Wood et al. (1976). Wood, Bruner, and Ross used the metaphor to show that teachers' support for individuals' learning is built up like a scaffold. Scaffolding makes it possible to achieve goals that cannot otherwise be achieved. After successfully establishing the support, the scaffold must be removed step by step. This process is called "fading". The term "scaffolding" is pedagogically used for assistants and support programs – often digital supports (e.g., Belland, 2017) – but there is no common understanding nor definition.

The concept of scaffolding is linked to the theory of Vygostkij (2015). In his work, he described the "zone of proximal development". This zone is between the learner's current and possible stages of development. It includes the range between what the learner can do on their own and what they can reach with competent support on their side.

According to Schiffl et al. (2019), scaffolds are temporary aids which are offered in lessons to empower learners to handle tasks which they could not process on their own. So, in future learning settings the learner can solve the task or problem on their own (Hammond & Gibbons, 2005); they reach the next possible stage of development. Scaffolds reduce complexity and put the focus on important characteristics of assignments (Wood et al., 1976). So, scaffolds help structure and facilitate the learning process.

The Cognitive Apprenticeship approach (Reusser, 1995) summarizes the embedding of scaffolding in the classroom and the roles that teachers and learners play in the process (see Figure 2.1). At the beginning of the learning process, the teacher plays an active role by showing how to do things correctly. In this phase of the lesson, the teacher explains the content and gives examples of successful implementation. When experimenting, it is often helpful if certain methods are demonstrated by the teacher. Thinking-aloud techniques can also promote understanding of inquiry, for example, when the teacher verbalizes everything they pay attention to when planning an experiment.

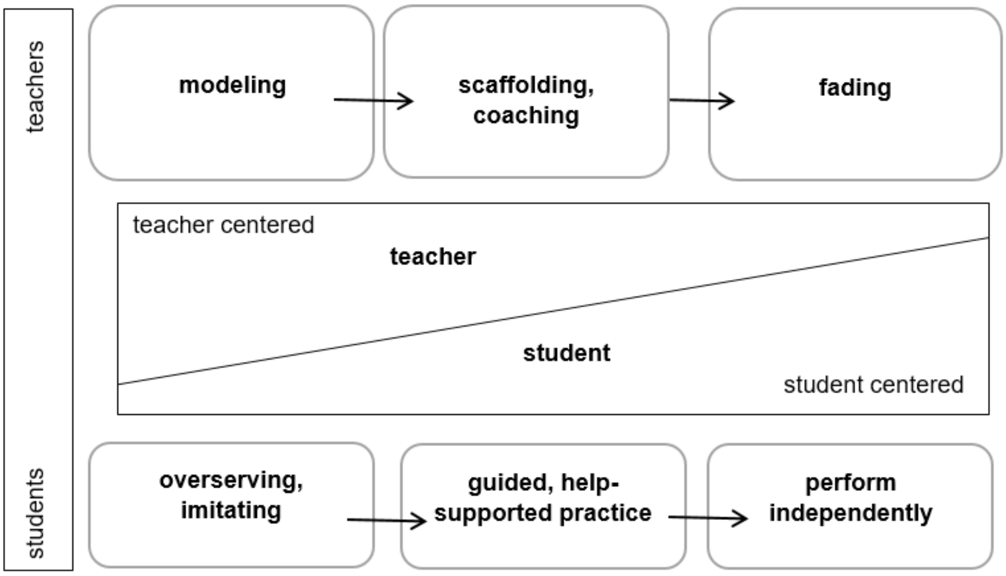


Fig. 2.1: Cognitive Apprenticeship (Reusser, 1995, p. 1)

The “modeling phase” is followed by the “scaffolding phase”, in which the teacher supports the learners to become active themselves. In this phase, learners practice with the support of the teacher. When the teacher recognizes that the desired competency has been achieved, they begin to dismantle the scaffold, that is, the help is slowly withdrawn. The term “fading” refers to the process of slowly removing support. The teacher changes role from coach to supervisor, engaging in formative assessment and giving feedback while learners are working on their own, until it is no longer needed.

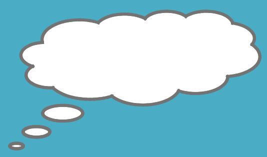
Scaffolding methods can be diverse (for some examples, see Chapter 6). First, it can be useful to think and discuss prior knowledge, as different ideas or different concepts play a role in learning processes. There are different ways of collecting learners’ ideas: for example, concept cartoons, mind or structure maps, or card queries. Pre-statement exams, in which learners formulate and justify their hypotheses, are also helpful for inquiry-based learning. These assumptions usually reflect learners’ ideas about a topic. After learners’ ideas and concepts have been collected, it is the teacher’s task to develop exercises accompanied by scaffolds. However, prompting learners’ prior knowledge can also itself be used as a scaffold.

There are two different categories of scaffold. Saye and Brush (2002) differentiate between “hard” and “soft” scaffolds. Hard scaffolds are static – for example, clue cards – whereas soft scaffolds are dynamic and process-orientated. The greatest difference between these two types of assistance lies in their preparation. Hard scaffolds must be prepared by the teacher before the lesson. The teacher needs to determine which parts of the assignments may be difficult for the learners and prepare help for them.

Example 2.3

Clue cards as an example of a hard scaffold

Clue cards can be used as prompts for different purposes. “Remember cards”, for example, activate prior knowledge so the learners can use this knowledge for new tasks. “Method cards” can also be used to explain a method which should be used, as can information tasks to give further information on a topic.



Remember card

We have already looked at the rabbit’s dentition together. The dog’s dentition looks different, but it consists of the same elements. Look at the labelling of the rabbit’s teeth again. Which elements do you also find in the dog’s teeth?

Soft scaffolds constitute situation-specific support which can be given by the teacher or peers “on-the-fly” (Tabrizi et al., 2019). Examples of soft scaffolds could include “blackboard cinemas” or learner experts. Blackboard cinemas offer learners the opportunity to come to the board at the front of the class to receive further input or an explanation of the work assignment. The teacher remains at the blackboard and gives the opportunity for learners to come forward voluntarily and only if necessary. There, the teacher can explain again what has already been explained or address possible individual barriers to learning in this context. It is called “cinema” because the setting can mimic a real cinema. Teachers can take a seat facing the blackboard and learners stand “on screen”. This method can also be modified using digital presentations instead of a classical blackboard. Learner experts can likewise take on the role of instructor here. The peer experts can provide assistance, for example, at stations prepared for this purpose. In this way, learners who need help can go to the station and ask for it. A practical method here is the use of expert cards, which learners can place on their seats after completing their work to indicate that they are offering help.

Teachers may vary between these soft and hard scaffolds depending on the setting and the tasks. The teacher needs to diagnose, adapt the support, and decide when and how the “dismantling” of the scaffold occurs. The use of digital media supports, such as simulations (Lehtinnen & Viiri, 2017), quizzes, or self-monitoring worksheets, is also a viable method.

Videos, models, and other visualizations can also be used thanks to digital terminals like tablets, smartphones, or notebooks. The teacher must prepare the websites or programs to be used by the learners. It is important to report the digital competencies of the learners in advance to avoid the use of digital technology generating further difficulties that impede learning. The use of digital terminals to research information or visualizations like models (simulations) – for example, models which demonstrate the subjects or models which show the finished product – can also happen spontaneously, on-the-fly. Such models can also be used during blackboard cinemas and on support stations, if the framework conditions allow, for example in tablet-supported school classes or in classrooms with adequate equipment.

Scaffolding has several advantages. Through the activation of learners, their chances of success may increase. So, this may also increase their motivation, which in turn can have a positive influence on the quality of the learning process (Deci & Ryan, 1993, 2008).

Summary

Learners are different in many characteristics. It is essential for good teaching to address these characteristics. The response to them can be summarized under the term "differentiation". In this book, we focus on the instructional level: how teachers can adapt their instruction to best support children's and young people's learning. There are different approaches to differentiation, which differ in planning and implementation.

One possibility to support learning is scaffolding. Scaffolds are temporary aids which are offered in lessons to empower learners to handle tasks which they could not process on their own (Schiffl et al., 2019). The aim is that through targeted scaffolding and subsequent dismantling of the scaffolds, learners will eventually be able to master their tasks by themselves. There are different types of scaffolds: hard and soft. Digital media can also provide support in the form of scaffolding.

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3 Inquiry-based learning

Fig. 3.1: Picture illustrating Example A
Picture: emmaws4s, 2013, available on Pixabay (License for free commercial use)

Fig. 3.2: Picture illustrating Example B
Picture: Patricia Lacolla, 2013, available on Pixabay (License for free commercial use)

3.1 What is inquiry-based learning?

Whenever teachers are asked to define inquiry-based learning, the responses they provide reveal that this common construct is conceived in different ways (Capps et al., 2016). Interviews show us that some teachers' definitions are consistent with what has been agreed by the science education community that the term should refer to. Some others entail a hybrid of informed and uninformed views of teaching science through inquiry, while some others pertain to misconceptions of what and how inquiry-based learning is promoted (interviews in preparation for this book with teachers from Cyprus, Austria, Finland and Germany; conducted in 2019; *N* = 30).
Before elaborating on what inquiry-based learning is, let us go through two science teaching illustrations (examples A and B in Example 3.1) to use as references while defining the term. It is well known that lessons directed to the same content can be designed very differently depending on the approach followed and on the roles of teachers and learners in the context of lesson implementation.

Example 3.1

Example A: The teacher writes the topic of the lesson on the blackboard, gives the learners the task of reading selected pages from their science book in an attempt to find out the necessary conditions for germination. The learners each read alone in their books and work out germination conditions. At the end of the lesson, they present their findings in a whole-class discussion format.

Example B: The teacher shows the learners germinated cress seeds in the teacher's hand. The teacher prompts learners to think of what seeds need for germination and the learners suggest their ideas in their groups and subsequently formulate questions (with the help of the teacher). In the lesson illustrated here, the question "What does seed need for germination?" is elaborated. The learners first generate hypotheses and plan an investigation to answer the question in group work. The student groups perform the planned investigation and discuss their results with their classroom peers.

When ones reads the two examples, the differences quickly become obvious. In example B, learners reach experimental findings following research methods similar to those used by scientists. The second example demonstrates a lesson that is more compatible with the inquiry-based learning approach.

Inquiry-based learning (IBL) is a learning approach – performed in a stimulating learning environment – in which learners construct new knowledge by conducting self-active investigations (University of Manchester, 2010). In this approach, learners identify their own problems and questions (ibid.). Therefore, the interest of the learners is taken into account (van Uum et al., 2016). Through the investigation, learners acquire new knowledge that is meaningful to them and inquiry skills (ibid.). The inquiry process involves learners using data as evidence (Capps et al., 2016) and it is crucial that learners communicate and justify their explanations (NRC, 2000; Pedaste et al., 2015). To use data, learners must plan, design or conduct an investigation (Capps et al., 2016). Methods of inquiry in science can be observation, dissection, experimentation or any other process that pertains to collecting data to answer a question or formulate an argument. We summarize below some of the key elements that shape the practice of IBL.

Elements that characterize IBL are:


the inquiry starts with a problem/question (generated by the learners or teacher)


learners plan the investigation (with the teacher's help if necessary)


learners perform investigations to get data


learners construct new knowledge that is meaningful to them through the inquiry


learners communicate and justify their results and explanations.

3.2 Why should inquiry-based learning be followed when teaching and learning science?

Having explained what IBL is, it is crucial that we now highlight the rationale behind choosing this approach in the context of science teaching and learning.

<u>IBL in response to changing pedagogical and educational thinking</u>

As early as the beginning of the 20th century, John Dewey (*1859, †1952) emphasized that scientific methods (inquiry) as methods to gain new knowledge had have too little importance in school. At the end of the 19th century, there was a widespread consensus to attribute the term “old education” to the method of passive learning and memorization, while accepting “new education” as an active and creative process (Oelkers, 2018, p. 31). The focus is no longer on the knowledge and curriculum, but on the child who is to be educated (ibid.). The initial point of Dewey’s pedagogy is not that of the child, but instead the practical processes of common life support (skills for democracy). Acting and thinking are aspects of this process (Schubert, 2019, p. 146). Dewey saw the benefit of applying scientific methods (inquiry methods) for students: “Since the mass of pupils are never going to become scientific specialists, it is much more important that they should get some insight into what scientific method means than that they should copy at long range and second hand the results which scientific men have reached” (Dewey, reprint 2001, p. 228). Scientific inquiry activities should be oriented towards students’ lives and help them get new knowledge as active learners in their searching for answers (Barrow, 2006). IBL can be seen in the sense of Dewey’s approach that learners use inquiry methods for acting and thinking to solve problems and questions related to their everyday lives.

Jérôme Seymour Bruner (*1915, †2016) coined the term “learning by discovery”. Learning by discovery is an educational approach that includes self-directed learning. Students find information in learning processes through active questioning and observations. They use their existing knowledge to aid learning processes (Schaub & Zenke, 2000). In discovery learning, the teacher has only an observational and assisting function (Stangl, 2020). In Bruner’s view, it is impossible to prepare a person with given solutions for any problems and situations that will affect them in future (Edelmann & Wittmann, 2019). Therefore, it is crucial that a person learns to solve problems (Edelmann & Wittmann, 2019; Stangl, 2020). Learning by discovery has connections to the constructivist learning theory.

From the perspective of constructivist learning theories, it is essential that learning is an active, autonomous and action-oriented examination of the subject matter, because learners can only build up an image of the world by themselves (Schnotz, 2011). Learning is a process of construction (experiencing the world itself), reconstruction (rethinking existing knowledge) and deconstruction (bringing into question: Could things be otherwise?) (Reich, 2012). In a similar way, IBL is a learning path, on which learners construct and reflect on knowledge by themselves. IBL is the dominant type of active learning because it enables learners' active investigation, which is essential to engaging learners with science (Rocard et al., 2007). Active learning has been proven to be more beneficial than traditional learning for science education (Freeman et al., 2014).

IBL is beneficial for teaching and learning

Through engaging learners in IBL practices, they are given the opportunity to develop scientific skills and acquire content knowledge (Crippen & Archambault, 2012; Edelson et al., 1999; Marx et al., 2004; Schneider et al., 2002). The positive effects of IBL have been found to be more beneficial for lower-level students (Marx et al., 2004). Another important benefit of IBL is that it has been linked with the development and preservation of learners' interest in science (Gibson & Chase, 2002; Osborne & Dilon, 2008). Indeed, when learners work in an IBL context, they do not think that science teaching and learning are boring, a perception that has prevailed strongly in the field of science education research (Alake-Tuenter et al., 2012).

IBL is in line with modern concepts of scientific literacy

Internationally, there is a lot of discussion about the objectives and contents of science education. These discussions have resulted in different definitions of scientific literacy (see more in Norris & Phillips, 2003). Many scientific literacy constructs include methods and processes of scientific knowledge discovery, whether as a claim to build understanding about scientific knowledge discovery (Bybee, 1997, 2002) or to develop metacognition (Shamos, 2002). Therefore, competencies for scientific knowledge discovery (inquiry competencies) are positioned internationally in the educational standards of several countries (e.g. see Table 3.1 regarding Austria, Cyprus, Finland, and Germany). IBL is a possible and suitable way to give opportunities to learn the inquiry process and to learn competencies for scientific literacy which are formulated in the educational standards.

Table 3.1: Scientific educational standards in line with IBL, focusing on experimentation. Example countries: Austria, Cyprus, Finland, and Germany.

Austria	***Cyprus***	***Finland***	***Germany***
Natural sciences (biology, chemistry and physics), lower secondary (BIFIE, 2011): Learners are able to … … do observations and measurements [E1] … ask research questions and suggest hypotheses [E2] … plan and carry out investigations and experiments, write experimental reports [E3] … analyze and interpret data from investigations and experiments [E4].	**Biology, grades 7–12 (Cyprus Ministry of Education, 2017a):** The general purpose of biology education across all grades is sorted into sub-objectives, which apply to each grade. Among these sub-objectives is the acquisition of scientific and experimental skills such as: … (ii) formulation of questions and hypotheses, (iii) design and execution of experimental approaches, (iv) recording, evaluation and analysis of measurements, (v) presentation of data, (vi) support or rejection of initial hypotheses, (vii) formulation of conclusions, generalizations and predictions, (viii) the capability to search for and develop alternative theories with the use of additional scientific data. **Chemistry, grades 7–12 (Cyprus Ministry of Education, 2017d)** Although there are enough experimental activities in chemistry, no specific learning objectives that explicitly promote the scientific skills for experimentation have been defined. There are only a few learning objectives for specific subject domains which imply the promotion of inquiry skills. For example: Grade 12: 3.16. Investigate through experimentation how the concentration of reactants and temperature affect the	**Biology, grades 7–9 (Finnish National Agency for Education, 2014):** The teaching and learning of biology also include working in nature and guiding students to familiarize themselves with the characteristics of biological information acquisition with the help of IBL. Approaches of field and laboratory work are used in examining nature. Experiential and experimental learning creates joy of learning and stirs learners' interest. Objectives of instruction: [O7] to guide the learner to develop their scientific thinking skills and understanding of causal relationships [O8] to guide the learner to use biological research equipment and information and communication technology [O10] to guide the learner to conduct research both in and outside of school. **Chemistry, grades 7–9 (ibid.):** The teaching and learning of chemistry are based on observation and examination of substances and phenomena connected to the learners' living environment. Conducting research has an essential importance for adopting concepts, learning research skills and perceiving the quality of natural sciences. Objectives of instruction: [O5] to encourage the learner to formulate questions about the	**Biology (KMK, 2005a):** At the end of secondary school level 1, learners are able to … … carry out investigations with suitable qualifying or quantifying procedures [E5] … plan simple experiments, perform these experiments and/or analyze the results of these experiments [E6] … apply steps of experimentation to generate explanations [E7] … discuss the scope and limitations of the investigation setting, steps and results [E8] **Chemistry (KMK, 2005b):** At the end of secondary school level 1, learners are able to … … identify and generate questions that can be answered with the help of chemical knowledge and investigations, especially through chemical experiments [E1] … plan appropriate investigations to verify assumptions and hypotheses [E2] … carry out qualitative and simple quantitative inquiries and record them [E3] … take safety and environmental aspects into account when experimenting [E4] … collect relevant data during investigations, especially in chemical experiments, or in search in literature [E5]

	speed of a chemical reaction (Cyprus Ministry of Education, 2020) **Physics, grades 7–12 (Cyprus Ministry of Education, 2017b)** One of the general purposes of physics education in grades 7–9 is to introduce learners to basic experimental procedures, among which are hypothesis formulation; design and execution of experiments; data interpretation; drawing conclusions; and communication. In grades 10–12, learners are expected to: - ask questions and formulate hypotheses that lead to different types of scientific investigations - create a written plan for an investigation - collect and organize data - interpret and evaluate data to draw conclusions - communicate the results from experiments in various ways, e.g., written reports, graphs and oral presentations. - explain that scientific research sometimes leads to unexpected results, which in turn lead to new questions and more investigations.	phenomena studied and to further develop the questions to serve as a basis for research and other activities [O6] to guide the learner to conduct experimental research in cooperation with others and to work safely and consistently [O7] to guide the learner to process, interpret and present the results of their own research and to evaluate them and the entire research process. **Physics, grades 7–9 (ibid.):** The teaching and learning of physics are based on observations and research on the natural and technological environment. Conducting research has an essential importance in adopting and understanding concepts, learning research skills and perceiving the quality of natural sciences. Objectives of instruction: [O5] to encourage the learner to formulate questions about the phenomena studied and to further develop the questions to serve as a basis for research and other activities [O6] to guide the learner to conduct experimental research in cooperation with others and to work safely and consistently [O7] to guide the learner to process, interpret and present the results of their own research and to evaluate them and the entire research process.	… find trends, structures and relationships in collected data, explain them and draw conclusions [E6] **Physics (KMK, 2005c):** At the end of secondary school level 1 learners are able, to … … generate hypotheses from simple examples [E6] … plan simple experiments, perform and record them [E8] … analyze collected data, possibly through simple mathematization [E9] … assess the validity of empirical results und their generalization [E10]

3.3 Inquiry-based learning cycle

Nowadays, IBL is the dominant teaching approach in science education and international educational research. From as early as three decades ago, scientific inquiry has been a prominent feature of science education reforms in the US, Australia and Europe (Minner et al., 2010). As a result, IBL was derived to denote how scientific inquiry is translated in everyday teaching and learning. However, one of the main challenges of introducing IBL in schools is that teachers do not feel confident to incorporate IBL in their instruction. Teacher interviews tell us that IBL is somewhat dominated by closed-inquiry assignments (interviews in preparation for this book). Abrams et al. (2007) attributed the problem of teachers not feeling confident to follow IBL in their everyday teaching practice to confusion over what constitutes inquiry. In the literature, there are many different definitions of inquiry. For instance, “scientific inquiry” is used to describe the processes that scientists follow in discovering and validating new knowledge, or the term “inquiry” may also be used to refer to IBL, i.e. how learners engage in active learning to construct their knowledge. In addition, "inquiry teaching" is usually cited as a general term with no distinct definition (Anderson, 2002; Minner et al., 2010). Taking into consideration the complexity of the definition of inquiry, teachers need to understand how scientific inquiry proceeds and how it should be adapted for educational purposes (NRC, 2000). In this book to ensure that IBL is operationally defined with a concrete meaning shared among all educators, we will use the IBL cycle pedagogical framework (Figure 3.3) of Pedaste et al. (2015).

Many different IBL cycles have appeared in the relevant domain literature; however, all these versions have relatively high overlap in terms of the phases (also referred to as “processes” or “steps”) involved in the cycle. These differences are primarily due to the use of different names for the same process or the breakdown of a process into smaller pieces. The IBL cycle pedagogical framework of Pedaste et al. (2015) was created in accordance with the existing versions of IBL cycles by identifying and synthesizing their core features. This framework was intentionally constructed to support the design and implementation of IBL instruction with online laboratories. Indeed, after its publication in 2015, many empirical studies involving the use of online experimental activities were conducted (see in this regard Efstathiou et al., 2018; Hovardas et al., 2017; van Riesen et al., 2018; Xenofontos, et al., 2019). In all these studies, the interventions integrated a learning scenario designed based on the phases of the IBL cycle. Besides the development of inquiry activities with online labs, many educators are using the IBL cycle pedagogical framework to design educational material that incorporates experimentation in a physical laboratory. For example, the recent educational reform in Cyprus included the IBL cycle as the core pedagogical framework for science teaching and learning in both primary and secondary education (Cyprus Ministry of Education, 2016; 2017c).

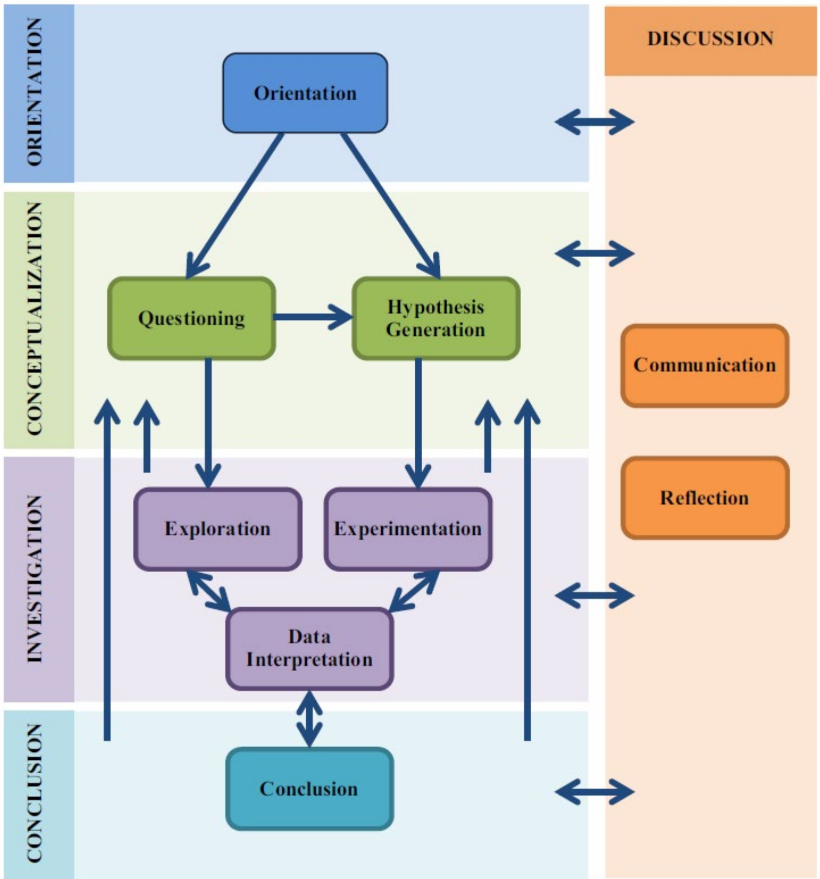

Fig. 3.3: Inquiry-based learning cycle pedagogical framework (Pedaste et al., 2015, p. 56)

According to the IBL cycle pedagogical framework, the inquiry-learning process comprises five phases.

The first phase is the *Orientation*, in which learners are introduced to the problem under investigation. The focus of this phase it to stimulate learners' interest and curiosity and to familiarize learners with the main variables of the domain and the problem and issues involved.

The second phase is the *Conceptualization*, during which learners become familiar with the concepts related to the problem at hand and follow two alternative sub-phases, namely the *Questioning* sub-phase or the *Hypothesis Generation* sub-phase. Both sub-phases are characterized by similar elements, so they have been merged as the *Conceptualization* phase. Specifically, they both rely on theoretical justification and involve defining independent and dependent variables. However, only the *Hypothesis Generation* sub-phase requires the description of a specific relationship between the variables at hand, while the *Questioning* sub-phase is more open-ended and seeks an examination of the relationships among variables. The selection of one of these sub-phases rather than the other depends on the nature of the IBL activity and determines the learning trajectory that learners follow in the next phase. In the *Conceptualization* phase, three different scenarios are possible:

(A) *Questioning* and continue with the *Investigation* sub-phase *Exploration*;

(B) *Hypothesis Generation* and continue with the *Investigation* sub-phase *Experimentation*;

(C) *Questioning* and continue with *Hypothesis Generation*.

The third phase, *Investigation*, involves three sub-phases, titled *Exploration*, *Experimentation* and *Data Interpretation*. The learner can go back and forth depending on the current state of the inquiry phase. The arrows back from *Data Interpretation* have been added to denote the dynamic nature of the cycle and to make more apparent the fact that it is not a linear process organized in a hierarchical order. Learners move to the *Exploration* sub-phase if they stated only a question in the previous phase or in the *Experimentation* sub-phase if they generated a hypothesis in the previous phase. Both sub-phases (*Exploration* and *Experimentation*) involve the design and execution of experimental procedures, while in the third sub-phase, *Data Interpretation*, they interpret the collected data and understand the relationships between variables. The focus of the *Exploration* sub-phase is the investigation of more than one pair of variables or possible relationships that were identified in the *Questioning* sub-phase, while the focus of the *Experimentation* sub-phase is the investigation of pair of variables/possible relationship specified in the *Hypothesis Generation* sub-phase.

In the fourth phase, *Conclusion*, learners draw their conclusions from the data collected and determine whether their research questions or hypotheses formulated in the *Conceptualization* phase are answered or supported by the findings of their investigation. Specifically, when the *Question* trajectory is being followed, the *Conclusion* phase leads to the identification of a relationship between variables, whereas when the *Hypothesis* trajectory is being followed, it ends with the confirmation or rejection of the hypothesis (confirmation or rejection of the posited relationship between variables).

The fifth phase of the IBL cycle, *Discussion*, involves communicating findings with others and/or controlling the learning process by engaging in reflecting activities. So, it is composed of two sub-phases, *Communication* and *Reflection*, which can occur throughout the IBL process. In the *Communication* sub-phase, learners present findings of an inquiry phase or of the whole IBL cycle to others and discuss them (discussion with others). In the *Reflection* sub-phase, learners describe, critique and evaluate the processes followed and/or the findings of a specific phase of or of the whole IBL cycle (inner discussion).

At this point, it is worth noting that the IBL cycle pedagogical framework allows three main learning trajectories (see Figure 3.3). If we leave out the *Discussion* phase from the trajectory (since it can be seen as a process that runs in parallel to each inquiry phase or as a process followed at the end of an IBL cycle), then the three main pathways are as follows:

1. Orientation – Questioning – Exploration – Data Interpretation – Conclusion

2. Orientation – Hypothesis Generation – Experimentation – Data Interpretation – Conclusion
3. Orientation – Questioning – Hypothesis Generation – Experimentation – Data Interpretation – Conclusion

In each of the three learning trajectories, it is possible from the *Investigation* phase to move forward to the *Conclusion* phase or back to the *Conceptualization* phase. This transition depends on the data collected during the investigation. Specifically, if learners have enough evidence to answer to the questions stated in the previous phase or confirm/reject the hypotheses formulated, then they move to the *Conclusion* phase. On the contrary, if the data collection is not successful, or if the data are insufficient, then they go back to the *Conceptualization* phase to reconsider their questions and/or hypotheses and repeat the experimental procedures in the *Investigation* phase. Moving back to the *Conceptualization* phase may also happen when learners conclude new ideas and/or possible relationships among variables related to the phenomenon under study. The learning trajectories and the retrospective pathways described above represent only standard possible routes. However, the actual pathway that learners will follow depends on the working scenario that is used and the context.

In summary, the IBL cycle pedagogical framework is centered on performing fundamental inquiry tasks, specifically identifying variables, making hypotheses, planning and conducting experiments, drawing evidence-based conclusions, communicating and reflecting. The organization of the tasks into five phases facilitates a continuous flow of IBL for learners. This structure allows the enrichment of the learning experience and helps learners to reach optimal learning outcomes, regardless of their current abilities, since it allows many options to provide guidance. Moreover, this structure helps teachers diagnose the difficulties their students have regarding specific tasks, make the inquiry tasks more familiar to students' learning style and differentiate and personalize the tasks based on learners' needs and abilities. Both the diagnosis of learners' abilities and the differentiation of inquiry tasks will be discussed in the following chapters of this book.

3.4 Domains of knowledge that can be facilitated through the inquiry-based learning approach

The description of the IBL cycle presented in the previous section reveals that engaging learners in the various phases of IBL can serve as a means through which they can practice, apply or develop different types of knowledge. Van Uum et al. (2016) point out, with reference to Duschl (2008) and Furtak et al. (2012), that scientific knowledge can be divided into four domains.

Conceptual domain: The conceptual (declarative) domain includes the knowledge of natural systems and phenomena (content knowledge, see Reiss, 2019): facts, conceptual constructs, theories and principles. For example: the factors needed for germination; the anatomy and physiology of a human heart; required elements in an electric circuit.

All activities in science are framed with conceptual knowledge, the prior knowledge needed to generate questions and hypotheses and the results of inquiry work.

Epistemic domain: The epistemic domain is the knowledge about the nature of science. The term "nature of science" refers to the methods of science, the epistemology of science and the relationship between society, culture and science. For example: knowledge of what an experiment is; comprehension of the need for repetition of measurements; understanding that scientific knowledge can be changed; understanding that science can improve our lives, etc.

The epistemic domain includes learners' knowledge of how scientific knowledge (this is also a part of the conceptual domain) is generated.

Social domain: The social domain includes competencies of critical thinking and of review (of one's own work and the work of others) and competencies for the exchange of findings and work in groups. Aspects of critical thinking include the evaluation and querying of results. In summary: competencies of collaboration (joint decision making), argumentation, and communication. For example, when learners complete an inquiry investigation, they communicate their results in several forms such as written reports, oral presentations to raise awareness and reflect on what can be further investigating by others or themselves.

Procedural domain: The procedural domain (process and methodological knowledge) contains competences for the sub-steps of inquiry. For example: competencies to formulate a research question, to state a hypothesis, to plan and execute an investigation, to collect data, to analyze data, to draw conclusions. By applying these skills during IBL, learners not only become more competent, but they also learn that these steps are the fundamental processes that define scientific inquiry. The distinction between epistemic and procedural is important, as study-based learning and teaching are often described as hands-on activities in which learners manipulate materials and collect data themselves, but do not participate in the process of evaluating the data (Furtak et al., 2012). In contrast to the epistemic domain, it is not essential in the procedural domain to understand epistemological justifications for the methods of scientific investigation. The PISA study defines the difference between procedural and epistemic as follows: Procedural is "being able to apply a control trial" and epistemic is "being able to justify why a control trial is important" (cf. Reiss, 2019).

The four domains will be of interest regarding the differentiation concept described later.

3.5 Degrees of openness in inquiry-based learning

In the IBL approach, learners should actively participate in the planning and implementation of the investigation (an argument based on the basics of Dewey, Bruner and constructivist learning theory). A procedure with ready-made "closed" inquiry instructions is contrary to the principles of IBL. That being said, closed inquiry instructions are fundamental to introducing inquiry methods; then, gradually, openness must follow (Baur et al., 2017). However, a completely open inquiry process tends to be overwhelming for learners (Kirschner et al., 2006). This was also highlighted by the teachers interviewed in the context of the *DifferentiatInq* research project. The teachers interviewed stressed that students encounter certain common and diverse difficulties with open inquiry. These include difficulties in formulating research questions, difficulties in formulating hypotheses, difficulties in planning experiments and difficulties in drawing conclusions.

In the interviews, the following question was asked: "If open experiments are carried out: what difficulties did students show during your experimentation lessons when planning and carrying out experiments on their own?"
Example answers include:
Teacher A: "… so when formulating a research question, I actually believe that many students are reaching their limits linguistically. That they simply have difficulty formulating a question in this way, which is then also verifiable."
Teacher B: "The students could not make hypotheses. You have to set guidelines for the students or I have to ask good questions so that they can formulate it themselves."
Teacher C: "… because students simply have difficulty working freely with specialist materials"
Teacher D: "… one is that observations and results are mixed …"
(interviews in preparation for this book, translated)

To protect learners from overload and to promote their independence in IBL ("openness"), there are two different types of approaches: linear approaches and non-linear approaches. Linear approaches include successive steps (levels) of openness and learners must climb step by step to become independent. There are linear approaches (frameworks) with three steps: step 1: openness of solution;

step 2: openness of methods and solution; step 3: openness of question, methods and solution (see Schwab, 1960, 1966). Other linear approaches consist of four steps: step 1: no openness; step 2: openness of solution; step 3: openness of methods and solution; step 4: openness of question, methods and solution (see Bell et al., 2005; Herron, 1971). With non-linear approaches (see Baur et al., 2020; Baur & Emden, 2020; Mayer & Ziemek, 2006) it is possible to consider the content of the inquiry itself (complexity, safety aspects), the competencies of the learners (learners may toned to be trained in new inquiry methods for the investigation) and the teacher's familiarity with the phenomenon in the design of the IBL process. In non-linear approaches, it is possible to open all "possible" sub-phases and to close all "impossible" sub-phases of the inquiry process (IBL cycle). The terms "possible" and "impossible" refer to whether learners have the necessary competencies to cope with the corresponding sub-phase independently. The degree of openness of one sub-phase can be chosen regardless of the degrees of openness of the other sub-phases. Despite the possibility of opening and re-closing sub-phases, non-linear approaches also aim to foster student autonomy.

To conceptualize the differentiation concept (Differentiation Tool) at the heart of this book, we have adapted the non-linear approach of Baur et al. (2020) to the IBL cycle framework of Pedaste et al. (2015). The approach includes different degrees of openness – *closed*, *moderately opened*, *opened*, *open* – for each sub-phase of the inquiry (adapted approach type, see Figure 3.4 and Figure 3.5). In Example Box 3.2 (p. 39) there is an example illustrating the different degrees of openness. For the adaptation of the non-linear approach of Baur et al., the phases *Orientation* and *Discussion* had to be added to the matrix. The non-linear approach of Baur et al. is structured as a table (matrix). To take into account the specificity of the phase *Discussion*, we divided the table in two. The phase *Discussion* (see Figure 3.5) entails connections to all other phases (see Figure 3.3).

		0 *closed*	1 *moderately opened*	2 *opened*	3 *open*
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
Conceptualization	**Hypothesis Generation**	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a hypothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
Investigation	**Data Interpretation**	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	Learners develop their own conclusion

Teacher-directedness → Student-directedness

Fig. 3.4: Degrees of openness – inquiry phases (adapted from Baur & Emden, 2020, p. 6)

		0 *closed*	1 *moderately opened*	2 *opened*	3 *open*
Discussion	**Communication**	---	Learners communicate according to given communication aspects	Learners communicate and teacher moderates the communication (giving help when necessary)	Learners communicate without help
Discussion	**Reflection**	Teacher reflects the inquiry	Learners reflect with given reflection questions	Learners reflect and teacher moderates the reflection (giving help when necessary)	Learners reflect without help

Teacher-directedness → Student-directedness

Fig. 3.5: Degrees of openness – discussion phase

Example 3.2

Germination experiment in different degrees of openness

The germination lesson example from the start of this chapter (Example 3.1, example B, p. 25) is used to illustrate the non-linear approach type. Since an experiment is used as an inquiry method in the example, a hypothesis is necessary (see Chapter 4), therefore path C (*Questioning* and continue with *Hypothesis Generation*) is described for the *Conceptualization.* Path B (*Hypothesis Generation* and continue with the *Investigation* sub-phases *Experimentation*) would also be possible.

Orientation:

closed	*moderately opened*	*opened*	*open*
Learners engage in a provided problem (phenomenon)	*Learners select a problem (phenomenon) from a pool*	*Learners identify a problem (phenomenon) with support (verbal or medial)*	*Learners contribute problems (phenomena) to the lesson*

The teacher shows the learners germinated cress seeds in their hand and prompts the learners to think of what seeds need for germination. This is part of the *Orientation* phase and is considered a *closed* action, since the teacher poses the topic of investigation. It would be *open*, for example, if a student were to arrive in class and say they were confused to see their mother had cultivated sprouts in the kitchen in a glass without soil. It would be *moderately opened* if the teacher presented the learners a film in which a gardener would be shown putting seeds in the ground, watering the seeds and, after a few days, small plants were to become visible. The figures for the model of the non-linear approach (Figure 3.4 and 3.5) show example methods. In the example of germination, a selection of several phenomena is not suitable. Therefore, a different method is used (other methods are explained in Chapter 6, Table 6.1). It would be *opened* if the teacher presented two pictures, with one showing seeds and the other showing a plant.

Questioning:

closed	*moderately opened*	*opened*	*open*
Learners engage in a provided question	*Learners select from a choice of questions*	*Learners develop a question with support (verbal or medial)*	*Learners develop their own question*

After *Orientation*, learners formulate (in our example) questions with the help of the teacher; so, the *Question* sub-phase is *opened*. It would be *closed* if the teacher were to give the question (e.g., “Can a seed germinate without soil?” or “What does a seed need for germination?”). It would be *moderately opened* if the learners were to be given the opportunity to select a question from a predefined set (e.g., “Can a seed germinate without soil?”, “Can a seed germinate in light?”…). If learners were to formulate questions without any help, it would be *open*.

Hypothesis generation:

closed	*moderately opened*	*opened*	*open*
Learners engage in a provided hypothesis	*Learners select from a choice of hypotheses*	*Learners develop a hypothesis with support (verbal or medial)*	*Learners develop their own hypothesis*

After stating or selecting the question, the learners formulate hypotheses. The *Hypothesis Generation* sub-phases can be *open* if learners formulate hypotheses without help. It can be *opened* if the teacher helps learners to express their ideas in the form of a hypothesis. It can be *moderately opened* if learners choose a hypothesis from a list of predefined hypotheses. It can be *closed* if the teacher provides the hypothesis under investigation.

Planning and conducting inquiry:

closed	*moderately opened*	*opened*	*open*
Learners work with provided instructions ("cook book")	*Learners select from a choice of instructions*	*Learners design an inquiry with support (verbal or medial)*	*Learners develop their own design*

In a similar way, the *Planning and Conducting Inquiry* sub-phase in our example can be organized following all the degrees of openness. It can be *open* if learners plan their investigation without any help. It can be *opened* if the teacher offers a set of materials, some of them being useful for the investigation while others not (example of a set of materials: seeds, soil, sand, boxes, lamps, cotton, beakers, water, Petri dishes, a fridge). It can be *moderately opened* if the teacher offers a set of materials, of which all are necessary, but leaves the use of the materials to set up the experiment to the learners (example of a set of materials for the hypothesis "Soil is needed for germination.": seeds, soil, cotton, water, Petri dishes). It can also be *closed* if the teacher gives the learners instructions on how to perform the investigation.

Data interpretation:

closed	*moderately opened*	*opened*	*open*
Learners analyze data according to a script, pattern, example	*Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)*	*Learners analyze data with support (verbal or medial)*	*Learners choose their own analysis of data*

After planning the experiment, the learners collect data and analyze them in the context of the *Data Interpretation* sub-phase. In the example of germination, this stage is not so difficult, because the learners only have to look at which Petri dish the seeds germinated in and which variables were provided in these Petri dishes and which in the other(s). Therefore, it can be designed as an *open* task (perhaps more closed when the quantity of germinated seeds is considered).

Conclusion:

closed	*moderately opened*	*opened*	*open*
Learners discuss a provided conclusion	*Learners select from a choice of provided conclusions*	*Learners develop a conclusion with support (verbal or medial)*	*Learners develop their own conclusion*

The next phase is the *Conclusion* and can also be designed in our example as *open*, *opened* or *moderately opened*. Learners can usually easily see whether the seeds have germinated or not and it is not so difficult for them to link this to the research question and the hypothesis, but in some cases the learners need guidance and the *Conclusion* phases must be *opened* or *moderately opened*. An *opened Conclusion* can be offered with prompts, for example: "(1) If your hypothesis were correct, in which of your test trials should you be able to see germinating seeds and in which not? (2) Compare your consideration (1) with your observation. (3) Is your hypothesis confirmed or not?" The *Conclusion* can be *moderately opened* if, for each possible hypothesis, an image is offered that shows all the necessary trials (test and control trials) and the observations that could be made if the hypothesis were correct. Learners have the tasks: "(1) Check that you have all the necessary trials (test and control trials) in your experiment. If yes, then: (2) Compare whether your observations match the observations on the image. If so, your hypothesis is proven, if not it is refuted."

Discussion:

	closed	*moderately opened*	*opened*	*open*
communication	---	*Learners communicate according to given communication aspects*	*Learners communicate and teacher moderates the communication (giving help when necessary)*	*Learners communicate without help*

	closed	*moderately opened*	*opened*	*open*
reflection	*Teacher reflects the inquiry*	*Learners reflect with given reflection questions*	*Learners reflect and teacher moderates the reflection (giving help when necessary)*	*Learners reflect without help*

Regarding the last phase, the *Discussion*, if learners are trained in communication and reflection, these sub-phases can be carried out in an *open* way, meaning they choose how they want to present their results and complete reflection tasks without guidance. If the learners are not trained, hints (*opened*) or prompts (*moderately opened*) to communicate and reflect are possible. Prompts can be a list of questions for reflection or a structure for the presentation.

Summary

Inquiry-based learning (IBL) is a learning approach that is in line with modern concepts of scientific teaching and is positioned in the educational standards of several countries.

IBL is characterized by the following elements: (1) inquiry starts with a problem/question; (2) learners plan the investigation; (3) learners do investigations to get data; (4) learners construct new knowledge through the inquiry that is meaningful to them; (5) learners communicate and justify their results and explanations.

The process of IBL can be described by the IBL cycle (see Figure 3.3).

There are four domains of knowledge that can be facilitated through IBL: conceptual domain, epistemic domain, social domain, procedural domain.

To promote independence ("openness") in IBL, a non-linear approach seems appropriate (see Figure 3.4 and 3.5).

Experimentation as one facet of inquiry will be explained in the following. Both IBL and experimentation in the sense of IBL will be the focus of the differentiation concept (Differentiation Tool).

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4 Experiments and how to use them for inquiry-based learning

An experiment is one of science's various methods of inquiry. Experimentation is the process of planning and performing an experiment and analysing the results (data) of the experiment. Other inquiry methods used in science are observation of nature, exploration, modelling, chemical analysis and dissection (Barzel et al., 2012; Bruckermann et al., 2017).

In school, experimenting is one of the essential methods in natural science classes for demonstrating phenomena and self-active learning to gain knowledge (e.g., Gropengießer et al., 2013). Therefore, they are one crucial facet of inquiry-based learning in science teaching (Baur & Emden, 2020; Schwichow et al., 2016). Experimentation in inquiry-based learning settings allows learners not only to learn scientific content (conceptual domain) but also to learn to do experimentation (procedural domain). Furthermore, learners practice learning about science by finding out how scientists do research and gain knowledge (epistemic domain). At school, experiments are often carried out in group work. Experimentation is therefore also a learning opportunity for collaboration (social domain) (van Uum et al., 2016). By playing the role of a scientist, learners learn to do science by working in an increasingly self-contained way. This is important because at school, learners should already be able to apply approaches and procedures used in scientific research (Bybee, 2002; Capps & Crawford, 2013; Nerdel, 2017; see also Table 3.1). Experimentation in school allows learners to explore the natural world using tools that are also used in science, so they come to understand the nature of science (NOS). NOS can be defined as a description of what science is, how science works, what characteristics scientific explanations have, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavours (McComas, 2015).

Besides experimenting, other inquiry methods are used in science as mentioned above. These other inquiry methods play a minor role in this book because here we are addressing differentiation in inquiry-based learning, with a focus on experimentation. We chose that focus because of the prominent role of experiments in science education and to exemplify a method of investigation in detail rather than in a cursory fashion.

4.1 What is an experiment? Definition and characteristics of an experiment

A natural-science experiment is a method investigating a natural phenomenon. There are also experiments in non-natural science, but these are not included in our book. An investigation in natural science means an intervention in a system or in an object (Gropengießer & Kattmann, 2006). The special characteristics of an experiment, apart from the fact that it is a kind of investigation, are as follows.

Causal research question: An experiment is the method to investigate causal questions. In a causal question, one asks about causal effects or, in other words, about possible effects of one variable on another. Examples of causal and of non-causal research questions are shown in the following Example Box (Example 4.1). Non-causal questions, like causal questions, are subject matter in science. If a non-causal question is to be investigated, other types of methods such as observation of nature, chemical analysis or dissection are required.

Example 4.1

Examples of causal and of non-causal research questions

Causal research questions:

- "What causes rust?"
- "What influences the photosynthesis rate?"
- "What conditions do plants need to grow well?"
- "How does the number of turns of a coil affect an electromagnet's magnetic field strength?"

Non-causal questions:

- "What are the differences between monkeys and humans?"
- "What ingredients does this chemical solution contain?"
- "Which of the presented rods made of different materials conduct heat well, which do not conduct heat so well?"

A causal research question can be qualitative or quantitative. Example of a qualitative research question: "Which factor(s) influence(s) photosynthesis?" A quantitative causal research question aims to determine how the quantity of a factor affects a phenomenon (the term "factor" is a synonym of the term "variable"). Example of a quantitative causal research question: "How does the amount of light affect photosynthesis?"

Hypothesis: An experiment needs a hypothesis or hypotheses (Pedaste et al., 2015). It is helpful for learners to examine only one hypothesis and not to examine several at the same time. A hypothesis is a justified assumption about the outcome of an experiment. A hypothesis is a possible answer to a research question. It is based on theory or on previous experiments. In most cases, hypotheses are formulated in causal relationships and conditions: "If…, then…"; "… leads to …"; "… influences …". If no hypothesis can be generated because there is no previous research, the hypothesis can be based on an exploration. An exploration can be performed to find variables for possible hypotheses (see *Exploration* in the inquiry-based learning cycle, Figure 3.3). A hypothesis can be qualitative or quantitative (see Example 4.2) and it can be directed or not directed.

Example 4.2

Kinds of hypothesis

Example from biology: The following research question will be investigated: "Which factor(s) influence(s) photosynthesis?"

Possible hypotheses in relation to the research question are:

Qualitative hypothesis: "Light is a necessary factor for photosynthesis."

Quantitative hypothesis:
→ ***directed:*** "High light intensity leads to a high rate of photosynthesis."
→ ***not directed:*** "The light intensity influences the rate of photosynthesis."

Example from physics: The following research question will be investigated: "How do the components of a coil affect the strength of an electromagnet's magnetic field?"

Possible hypotheses in relation to the research question are:

Qualitative hypothesis: "The presence of an iron core in the coil strengthens the magnetic field."

Quantitative hypothesis:
→ ***directed:*** "The more turns of the coil, the stronger the magnetic field."
→ ***not directed:*** "The number of turns affects the strength of the magnetic field."

Example from chemistry: The following research question will be investigated: "How can the gas development in a soda water bottle be accelerated?"

Possible hypotheses in relation to the research question are:

Qualitative hypothesis: "The addition of sugar has an influence on the speed of gas development in soda water."

Quantitative hypothesis:
→ ***directed:*** "The higher the ambient temperature, the stronger the gas development in the soda water."
→ ***not directed:*** "The ambient temperature influences the strength of gas development in the soda water."

Control-of-variable strategy: Before undertaking the practical part of an experiment, one must clarify which factors (variables) are to be measured. The experimenter must identify the dependent and independent variable(s). The dependent variable is also called the "measured variable". In other words, the effects on this variable are measured (outcome). The independent variable(s) represents the factor (factors) which is (are) varied systematically according to the respective hypotheses. It is the cause for changes in the dependent variable. In most cases, there are more than one independent variable which could affect the dependent variable. In such cases, it is important not to vary more than one independent variable at a time for causal conclusions to be made possible (Chen & Klahr, 1999). There is a tendency for learners to vary too many variables, making it difficult for them to draw a conclusion (Glaser et al., 1992). Variables (factors) that are not included in the hypothesis must be controlled, they must be kept unchanged during the experiment.

Test and control trials: An experimental setting (a test series) includes different trials (set-ups) for experimental control (Hammann et al., 2008). In a qualitative experiment (research question and hypothesis are qualitative) there are test and control trials. The literature does not clearly define which of the experimental trials is the test and which is the control trial. However, it is undisputed that both are needed in an experiment (explanation follows). We will apply the following working definition: The control trial is set up like the natural situation present in the phenomenon and is set up to see whether the phenomenon/natural situation (which is the basis of the research question) can be reproduced with laboratory material. Only in the test trial is the independent variable varied (see Figure 4.1a and Figure 4.2a). Variation (removing a factor, adding a factor, reducing or increasing the amount of a factor) is performed to investigate the influence of the varied variables. All other variables will be not varied (see control-of-variable strategy). After running the experiment, all trials – test and control trials – are to be compared. If the phenomenon is observed in the control trial but not in the test trial, the independent variable has an influence (see Figure 4.1b and Figure 4.2b). If more than one independent variable is investigated, more test trials are necessary (see Figure 4.3).

Research question:
What influences the rusting of iron?
Hypothesis:
Water influences the rusting of iron.

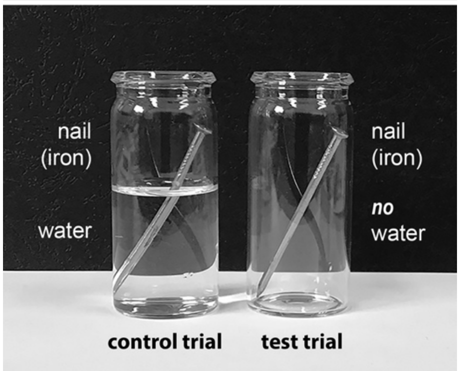

Fig. 4.1a: Test and control trials

Fig. 4.1b: Experimental result

Research question:
What influences germination?
Hypothesis:
Soil influences germination.

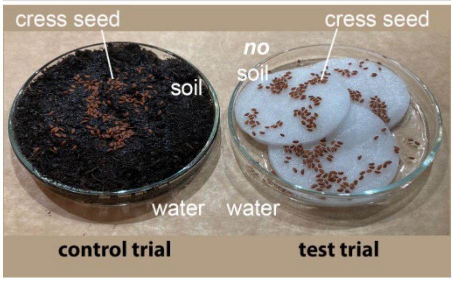

Fig. 4.2a: Test and control trials

Fig. 4.2b: Experimental result

Research question:
What influences the rusting of iron?
Hypothesis:
Water and light influence the rusting of iron.

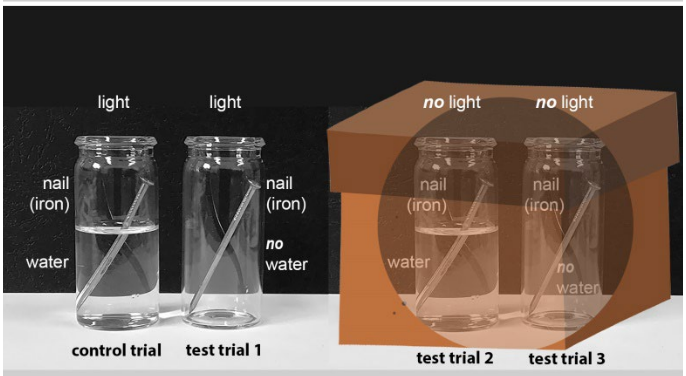

Fig. 4.3: Experimental setting of an experiment with two independent variables

In a quantitative experiment (research question or/and hypothesis is/are quantitative) there is no clearly defined control trial, but many test trials (see Figure 4.4 and Figure 4.5). In the test trials of the setting, the independent variable is varied stepwise. All other variables are kept constant (see control-of-variable strategy).

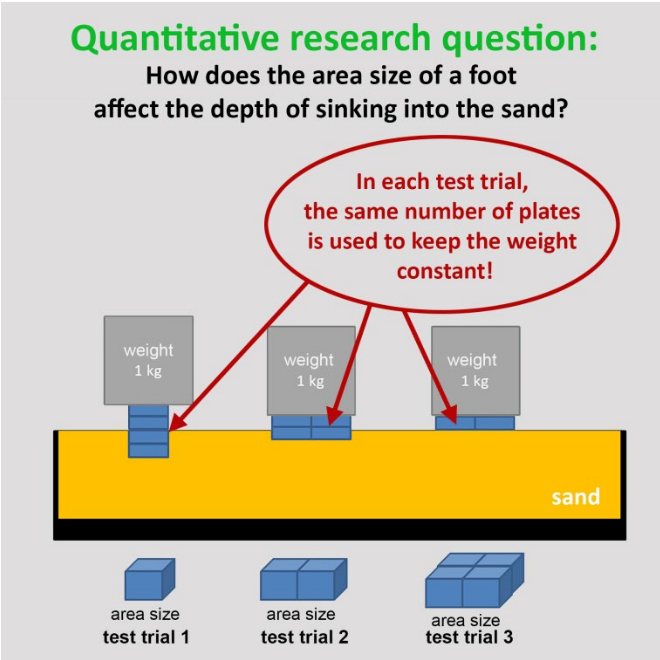

Fig. 4.4: Experimental setting of a quantitative experiment

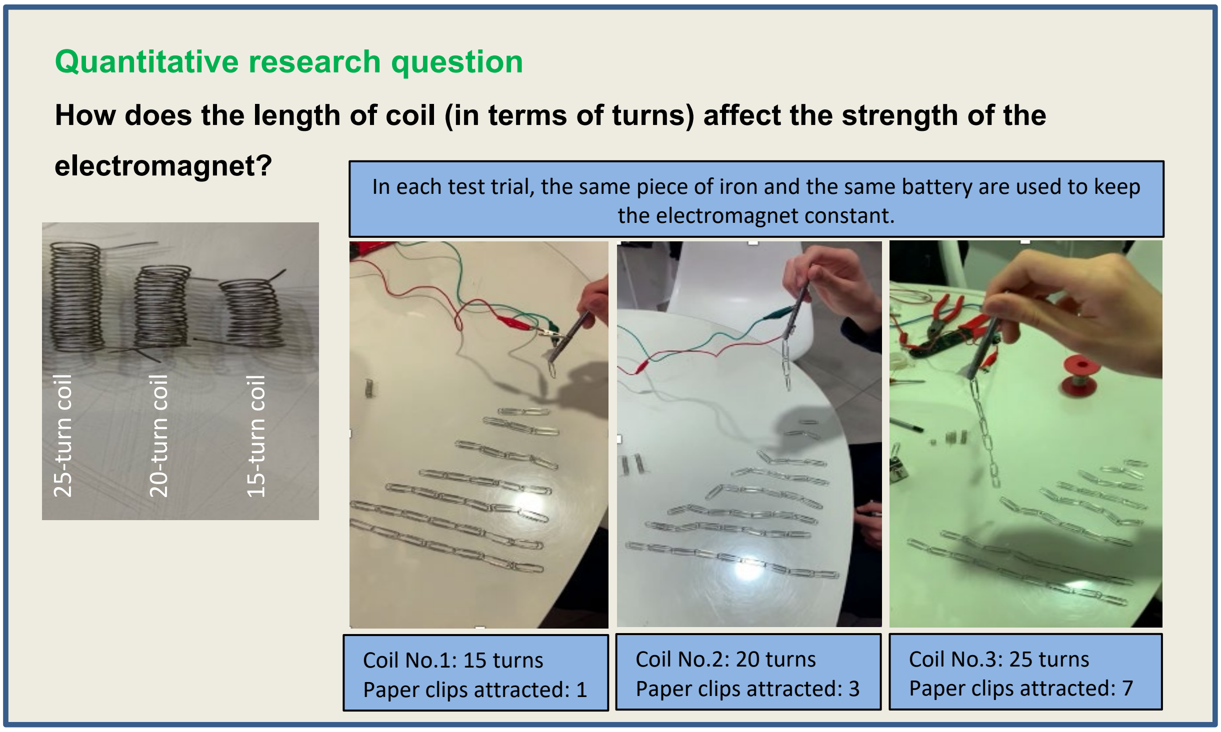

Fig. 4.5: Experimental setting of a quantitative experiment

Quality criteria: Experimentation in scientific research must meet three quality criteria: objectivity, reliability and validity (Döring & Bortz, 2016). As far as possible, these factors should also be considered during experimentation at school.

Objectivity means that the results of an experiment are independent of the people performing the experiment. No subjective feelings, biases or prejudices should influence the results of experiments.

Reliability stands for reliable and trusty results. A crucial component of reliability is repeatability. Repetitions of the experiment should obtain comparable results, even when other people are conducting the experiment. This requires the control (keeping constant or eliminating) of all possibly influencing factors apart from the independent variable. Measurement precision is achieved when suitable measuring devices are used.

All the data must be valid. Validity means that one ensures that one can measure exactly what one wants to examine. Validity includes precise questions, hypotheses and sufficient repetitions of the experiment.

Characteristics of an experiment

Causal research question:	The research question investigates causal effects.
Control of variables:	All variables that are not investigated must be controlled.
Hypothesis:	For experimental planning, a hypothesis is necessary.
Test and control trials:	For experimental control, different trials are necessary.
Quality factors:	The factors objectivity, reliability, validity are crucial quality factors of an experiment. Results must be repeatable.

4.2 Using experiments in inquiry-based learning

In the literature concerning education and methods in science teaching, there are diverse conceptions of experiments and experimentation at school (e.g., Barzel et al., 2012; Urhahne et al., 2008). We will use the concept of inquiry-based learning and the inquiry-based learning cycle (see Chapter 3) for experimentation. In Chapter 3 (IBL), Figure 3.3 shows these phases in summary; they are now presented in detail for experimentation. The following Table 4.1 shows the different phases in detail;

each phase is illustrated by means of an example, namely the question of which factors influence photosynthesis. The experimental design is shown in Figure 4.6.

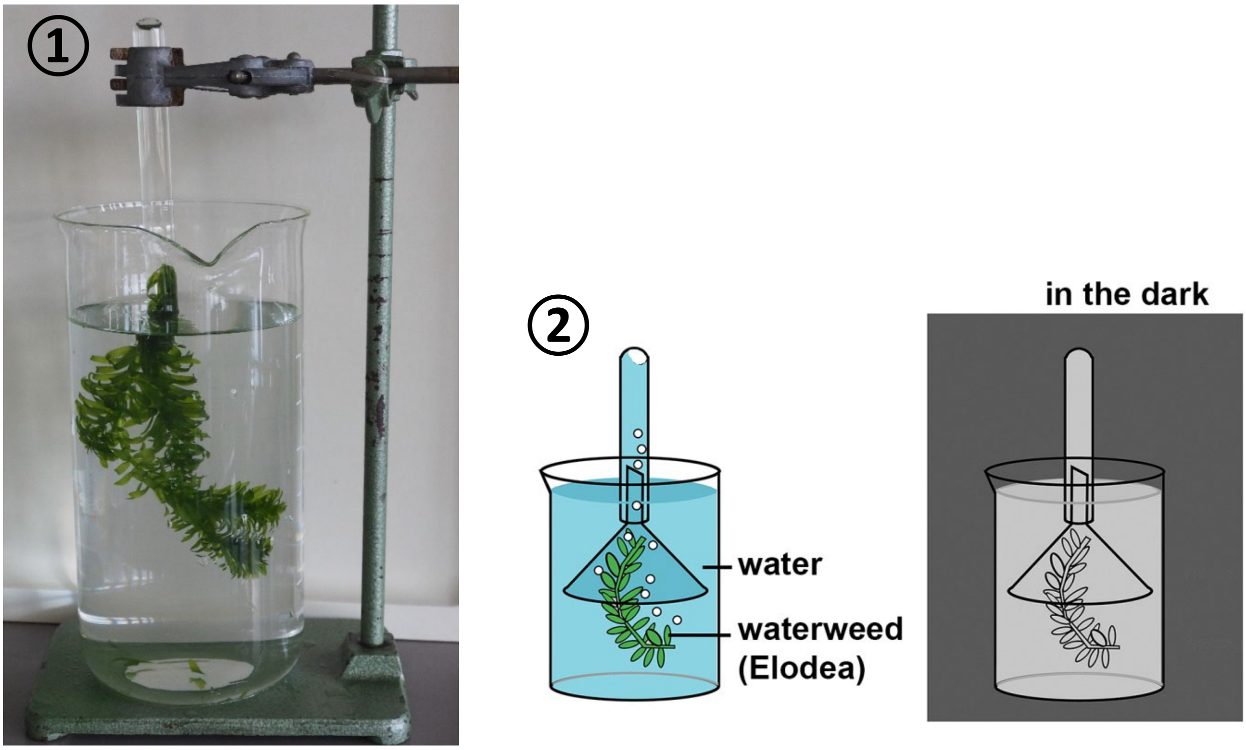

Fig. 4.6: (1) experimental design for the investigation of oxygen production during photosynthesis; (2) experiment for investigating photosynthesis (pictures on the right from Baur et al., 2017, p. 6, image changed)

Table 4.1: Phases of experimentation

Phase	Explanation	Example: Photosynthesis
1st phase: Orientation	A phenomenon is presented to the learners.	The Canadian waterweed (*Elodea canadensis*) lives submerged in freshwater. It produces small gas bubbles (oxygen) during photosynthesis. This gas production can be used to investigate photosynthesis at school. The phenomenon "gas bubble production by a green freshwater plant" is presented to the learners.
2nd phase: Conceptualization	***Sub-phase: Questioning*** In open inquiry-based learning approaches, the learners´ task is to express causal questions concerning the phenomenon, which can be answered using an experiment.	Learners ask questions like "Which factor is necessary for gas production?", "Which factors affect the amount of gas produced?".
	Sub-phase: Hypothesis Generation The hypothesis is deduced from the question or problem based on previous knowledge, everyday life experience, and learners' preconceptions. It is phrased as a prediction of a cause-and-effect relationship. The learners are requested/asked to give reasons for their prognoses, so they arrive at an educated guess.	Now the learners formulate hypotheses, such as "We suppose that the production of this gas requires daylight.".
3rd phase: Investigation	***Sub-phase: Experimentation*** The learners develop an experimental design. They plan their test or experimental setup and timetable. In this phase it is crucial that the strategy of controlling variables is followed strictly. It is critical that learners vary only one independent variable at a time, all other possible	Two trials are necessary (Figure 4.6): 2 shoots of waterweed, 2 long beaker glasses, 2 test tubes, 2 glass funnels, tap water. The beaker glasses are filled with tap water and one freshly cut shoot is placed in each glass, upside down. The test tubes are filled

	variables being kept under control, meaning they are kept constant or are eliminated. Control trials must be carried out and, the extent possible under school conditions, at least some repeats should be performed.	completely with tap water, then they are placed over the end of the shoot without losing water, so that gas bubbles are caught in the test tube and collected in the tip. 1. 1 trial (set-up) is placed in direct sunlight. 2. 1 trial (set-up) is placed in complete darkness.
	Sub-Phase: Data Interpretation The data are collected, prepared and visualised as tables, graphs, diagrams, etc. In addition, the results should be recorded in a written report.	After some time, production of gas (oxygen) is measured as mm gas collected in the upper end of the test tube. In the trial with daylight, gas is measurable; in the trial with darkness, no gas is measurable.
4th phase: Conclusion	In the last phase of experimentation or inquiry-based learning, the learners are advised to compare their results with the questions and hypotheses they had phrased in the beginning. So, they can find out/detect whether the hypotheses have been verified or been falsified. In the latter case, the hypothesis must be modified and the experiment may need to be repeated.	The learners compare the gas production in light and darkness. So, conclusion drawn is that the waterweed in daylight produces gas bubbles (oxygen), while in darkness there is no gas production. The hypothesis "We suppose that the production of this gas requires daylight" can be confirmed.

When the results of an experiment are compared to the question and hypothesis, this leads to a cycle. This cycle can be repeated several times if modifications of the hypothesis are needed and an appropriate modified experiment has to be undertaken.
In addition, one or more explorative phases can be performed in advance. In these explorative phases, the learners gain knowledge about the phenomenon, which can be necessary for them to be able to formulate a proper hypothesis. It is obvious that, in this case too, a systematic way of working and careful documentation are required to make useful additions to previous knowledge.

4.3 Observable errors and learner problems when experimenting

Experimentation is a complex process with its facets of thinking, planning, handling and drawing conclusions, each relying on different kinds of competencies. It is obvious that learners cannot perform experimentation spontaneously – they need proper advice and training. For teachers, it will be helpful to know in advance the typical problems and errors their learners will have to deal with. Therefore, after explaining in this chapter what the characteristics of an experiment are, we will give a picture of learners' problems and errors when they plan and conduct experiments, and derive how to counter them in class.
An assessment of learners' performance can be done with a focus on competencies (What are the learner's abilities?) or, on the other hand, in terms of learners' errors and problems (What are the learner's learning problems?) (Baur, 2015). In this sense, errors should not be understood as a deficit, but as a learning opportunity (Metcalfe, 2017; Schumacher, 2008). There is a lot of research that deals with the identification of learners' problems and errors when experimenting. Some of the central results are presented in the following in a structured manner according to the sub-phases of experimentation. So far, there have been very few scientific clarifications of the reasons and derivation of teaching actions with regard to identified learner errors. So, only advice based on interpretations and experiences can be given in this book.

4.3.1 Sub-phase: Questioning

With regard to learners' problems and errors in asking a research question in the field of experimentation, there are so far only few empirical findings. One of the central findings is that learners often do not ask causal questions, but instead content-related questions (Cuccio-Schirripa & Steiner, 2000; Hofstein et al., 2005; Neber & Anton, 2008) – for clarification of causal versus content-related questions see Example 4.1 on p. 46. For experimentation, causal questions are necessary. The reason for this learner error could be a misconception (or preconception) among learners about goals and the structure of a scientific research question. For science teaching it seems to be decisive to address what a research question is, what the function of a research question has, what kind of research questions there are (content-related questions, comparison questions, causal questions – see Dillon, 1984), and which kind of research question leads to which type of investigation. In addition, it seems necessary to train the formulation and asking of research questions. If it becomes apparent during assessment by a teacher that there are learners who make errors or have problems, scaffolding and differentiation must be used in this sub-phase. Also, extended exercises and training to formulate research questions could be helpful.

4.3.2 Sub-phase: Hypothesis Generation

Learners' skills, problems and errors in stating a hypothesis are addressed by many research papers. Key findings are that:

- many learners plan and conduct their experiments without hypothesis (Dunbar & Klahr, 1989; Millar & Lubben, 1996; Zhai et al., 2013);
- from the point of view of many learners, the goal of an experiment is to create an effect (Hammann et al., 2006; Schauble et al., 1991). Therefore, many learners formulate a desired effect in their hypotheses (example of such a hypothesis: "I assume that the plug of the test tube will fly off explosively.");
- students often formulate positive hypotheses (if more… then more…). Negative hypotheses (if more… then less…) are rarely formulated (Kanari & Millar, 2004);
- learners only formulate hypotheses that are plausible to them (Hammann et al., 2006; Klahr et al., 1993);
- a number of learners change their unclarified hypotheses during the experimentation process (Baur, 2021).

The reasons behind these difficulties and errors in stating a hypothesis could be misunderstandings (preconceptions) about the goals and structures of hypotheses. Perhaps it is unclear to learners what general meaning a hypothesis has in the experimentation process (it is not possible to plan an experimental setting without a hypothesis because it is not clear which variables have to be varied and which must be kept constant). A possible reason for the formulation of positive hypotheses by learners is that this kind of hypothesis is usually found in textbooks and in the classroom (Kanari & Millar, 2004). As in the sub-phase *Questioning,* it seems crucial that exactly what a hypothesis is should be made explicit in the classroom, in addition to what meaning it has and how it is linked to the research question (a hypothesis is a possible answer to the research question) and to the experimental setting. Just as in the sub-phase *Questioning,* it is crucial that, if the assessment by a teacher reveals that there are learners who make errors or have problems, then differentiated practice is offered.

4.3.3 Sub-phase: Experimentation

Learner errors and problems when planning and conducting experiments are manifold. Findings from literature concerning this sub-phase include the following.

- Many learners plan experiments that include only one trial (see clarification in this chapter of test and control trials on p. 48). Therefore, learners cannot recognize the influence of the independent variable(s) (Hammann et al., 2006; Hammann et al., 2008). While some learners do not include a control trial (Germann et al., 1996), others do not include a test trial in which the independent variable is modified (Chen & Klahr, 1999).
- Very often, learners disregard the control-of-variable strategy (Hammann et al., 2006; Kuhn & Dean, 2005; Schauble et al., 1991; Siler & Klahr, 2012).
- Some learners forget to include a necessary variable (e.g., yeast in a yeast experiment) (Baur, 2021).
- Several learners vary laboratory equipment in their various trials (test and control trials) that belong to a setting (ibid.) and thus create different conditions in the related trials, which may make them no longer comparable. For example, in yeast fermentation experiments in which gas development is measured by blasting off a stopper, it would be wrong to use Erlenmeyer flasks with different volumes in the control and test set-ups.
- Learners often do not consider controlling the amounts of substances (Baur, 2018) – for example, in experiments with yeast, amounts of yeast in the test and control trial must be equal.
- Often, learners tend to investigate multiple variables at the same time and would therefore have to plan a multifactorial experimental setting, which is overwhelming for learners when planning and reasoning (Glaser et al., 1992).
- In many cases, learners only try things out without working strictly scientifically (Hammann et al., 2008; Meier & Mayer, 2012; Wahser & Sumfleth, 2008).
- Learners rarely repeat their measurements, so there is no measurement error control (Lubben & Millar, 1996).
- Some learners have difficulty using (simple) measurement and laboratory equipment correctly (Kechel, 2016).

The causes of some of these errors and difficulties can be a lack of learner understanding about the control-of-variables strategy and about the need for control and test trials. The control-of-variables strategy also includes the use of identical laboratory equipment and the consideration of equal amounts of substances (if this is not the variable being varied) in the test and control trials. Also, an understanding of the learners for the averaging of measurement results to minimize measurement errors is certainly not available per se (without explanations). The handling with measuring and laboratory equipment requires constant training and practice. Therefore, it seems important that learners learn, in the classroom, the control-of-variables strategy, the need for control and test trials, and the sense of measurement repetition. The teacher should advise the learners to vary only one variable and avoid multifactorial experimental settings. As already mentioned in the previous sub-phases, if errors and difficulties in this sub-phase become clear in the formative assessments, possibilities for adapting concepts or further exercises must be made via differentiation and scaffolding.

4.3.4 Sub-phase: Data Interpretation

Errors in data interpretation are often triggered by learners' content-related preconceptions:

- if the data found do not match learners' expectations, some learners assume an error in their own experiment (Ludwig et al., 2019; Wahser & Sumfleth, 2008; Chinn & Brewer, 1998);
- many learners ignore data that do not fit with their expectations (Chinn & Brewer, 1993; Gauld, 1986; Kuhn, 1989; Schauble et al., 1991; Watson & Konicek, 1990);
- A lot of young learners, as well as many adults, tend to stick to their hypotheses and try to confirm them (Chinn & Brewer, 1993; Klayman & Ha, 1989; Wason, 1960).

There are also method-related learner errors:

- if learners take repeated measurements, they often choose the first or last measurement result as the final result, or a value between the highest and lowest measurement result, rather than calculating the arithmetic mean (Kanari & Millar, 2004; Lubben & Millar, 1996; Masnick & Klahr, 2003);
- learners often swap observation and conclusion (Boaventura et al., 2013).

In science lessons, therefore, there is a need to talk with learners about objective data analysis. Another important aspect of teaching is to clarify with the learners that, in an experiment, unexpected results often occur and are normal. Perhaps it is essential that a teacher explicitly explains to their learners that even refuted hypotheses provide results and are therefore not "wrong". It seems necessary to discuss the difference between an observation and a conclusion, and both must be trained. The reasons for measurement repetition must be addressed. As in all other sub-phases, it is important that differentiated exercises and scaffolding are offered when difficulties by the learners are apparent.

Summary

Experiments play an important role in science education as a fundamental inquiry method. They are characterized by a causal research question, the formulation of hypotheses, planning and conducting the experiment under controlled conditions (test and control trials, control-of-variables strategy), and interpretation of the data collected. Finally, the result of an experiment is compared to the hypothesis, enabling one to examine whether the data support or falsify the hypothesis. Of course, the quality factors of scientific work such as objectivity, reliability, and validity also apply for experiments at school.

It seems very helpful to use the knowledge of learners' difficulties and errors to plan and design lessons. This allows for changing leaners' possible preconceptions or for counteracting a lack of knowledge, and for offering targeted thematizations and exercises in the classroom.

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5 Assessment for inquiry-based learning

5.1 Introduction: assessment as a pre-condition for differentiation

If teachers want to differentiate and adapt their teaching to learners' needs, they need to know about those very needs in the first place. So, if teaching is to be adapted to learners' performance, teachers need know about each learner's competency levels and about the factors enabling their learning, but also about the obstacles hindering the same. Such an assessment offers teachers the possibility to acquire this vital knowledge. Teachers can choose between different methods for assessing learners' achievements and learning paths according to different situations and goals. Knowledge about learners' competencies can be used either to evaluate learning results or to foster learning processes (Black & William, 2018). During a lesson, assessment is usually used quite spontaneously, for example when teachers ask questions to get a clearer picture about learners' ideas or when teachers observe their learners working on their own (Shepard, 2019). This kind of assessment works well for gaining information to foster learning. Besides these "on-the-fly" methods, assessment is often a planned process whereby teachers think about what they need to know about their learners to develop the latter's competencies or whereby they note learners' achievement and then choose an adequate method. Written tasks and the analysis of work samples are examples of planned assessment, as they need to be prepared for in advance. Planned assessments work well for evaluating results, for example for noting and developing learners' competencies. In some countries, more official kinds of assessments also exist, such as standards assessment or official tools that teachers can use voluntarily to assess their learners' competencies.

In this chapter, first, some important concepts of assessment are discussed. Then, with the focus on assessment in the classroom, different methods for assessment in inquiry-based learning situations are presented, whereby methods of assessment through teachers and peers and self-assessment are taken into account.

5.2 Formative and summative assessment

Example 5.1

What comes to your mind when you think about the word "assessment"? It could be an image of a classroom full of learners completing their matriculation exams, which are then assessed to determine who will get to start their studies in university and who is left out. Or it could be an image of a teacher telling a learner: "I see from your work that are doing great in formulating different research questions, but it would be good for you to look more closely into how a controlled experiment is carried out."

These two images of assessment are both valid and correct, but they portray different purposes of assessment.

The first image described in Example 5.1 is an example of *summative assessment* or, to be more precise, the summative purpose of assessment. The aim of summative assessment is to provide a report or snapshot of a learner's knowledge and skills at a certain point in time. This can be done via collecting, interpreting, and reporting different forms of evidence for learning (Dolin et al., 2018). Evidence can be collected, for example, by administering tests or exams, creating a portfolio of learner work or by summarizing different observations (whether in written form or just as mental notes internal to the teacher) and recordings collected over a longer period. The interpretation or judgement of evidence is done in relation to the learning goals the learners should have achieved at the time point of assessment, such as the end of school year. The reporting of learning can have different uses: the most common is probably a school report given to each learner at the end of each semester. The scores on the report are then used, for example, to determine which learners get to continue their studies in university programs or in a particular secondary school track (see Example 2.2 in Chapter 2) with limited capacity. Sometimes, the results of a summative assessment are used to evaluate different teachers or schools, which can affect their reputation or funding.

On the other hand, the second image described in Example 5.1 is an example of *formative assessment*, in other words the use of assessment for formative purposes. The aim of formative assessment – assessment *for* learning – is to support learning when it happens, instead of reporting learning outcomes afterwards as summative assessment – assessment *of* learning. So, formative assessment has also been called "ongoing assessment". Formative assessment can be illustrated by the questions "Where is the learner going?", "Where is the learner right now?" and "How to get there?" (Black & Wiliam, 2009; Hattie & Timperley, 2007) whereas summative assessment can be seen as looking back: "What has been learned up until this point?". Different emphases for formative assessment have been proposed (Bennett, 2011). Some stakeholders have seen formative assessment more as an instrument or as a diagnostic test bank (Pearson, 2005), while the emphasis has more recently been on the view that formative assessment is a process which provides "a qualitative insight into students' learning" (Shepherd, 2008). A critical aspect of formative assessment is that information about a learner's performance is used to promote their learning in the future, that is, the information is used as a basis for decisions about teaching and learning. As Black and Wiliam (2009) put it:

"Practice in a classroom is formative to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited."

When taking a closer look at the process of formative assessment outlined by Black and Wiliam (2009) we can distinguish three different processes: 1) eliciting evidence of learner achievement, 2) interpreting this evidence, and 3) using this evidence to make better, or better-founded, decisions about the next steps of instruction than would have been made without the evidence. Even before these processes are enacted, the learning goals and the steps needed to progress towards these goals should be made clear for both the teacher and the learners (Dolin et al., 2018; Ruiz-Primo, 2011).

Eliciting evidence about learner achievement can happen through different methods. Teachers can simply observe learners while they are working, ask questions to probe for learner understanding, and engage in discussions with them (Ruiz-Primo & Furtak, 2007). Eliciting evidence can also happen, for example, through studying learners' notebooks or reports from a longer period or by giving the learners tests or quizzes (Dolin et al., 2018). Even though the definition by Black and Wiliam (2009) and in other studies of formative assessment (Dini et al., 2020; Ruiz-Primo & Furtak, 2007) frames teacher eliciting as an active process akin to teacher questioning, other studies highlight the role that unelicited learner contributions can have on formative assessment discussions (Louca et al., 2012; Nieminen et al., 2020). In our interviews for the purpose of this book, the teachers reported that they elicited evidence from learners by observing learners during lessons, by asking them questions, by studying their research reports or worksheets, or by having them produce a portfolio about what they have learned.

Interpreting evidence is often an implicit, internal process whereby the teacher makes sense of the evidence about learner achievement (Dini et al., 2020). This process includes making judgements based on the evidence and its correspondence to the learning goals, other learners, and the abilities of each individual learner (Dolin et al., 2018).

The final process is to use the judgement based on the elicited evidence to make decisions about the next steps of instruction. This can mean that something about the planned teaching progression needs to be changed altogether. For instance, the teacher's judgement could be that the learners still need more practice before moving on to a new topic. Often, this decision about the next step is to offer feedback to the learners. The aim of this formative feedback is to provide learners with information about their achievement and especially how they can improve their work. This feedback should be more than just a grade. Butler (1987; 1988) found that giving grades, with or without additional comments, was less effective in improving learners' work than giving only comments. For formative assessment to be successful, teachers need to know how to elicit valid and good-quality evidence from learners, how to make proper judgements based on this evidence, and how to make well-founded decisions based on this judgement. In our interviews teachers reported that they used information gathered from learners to both provide on-the-fly feedback and to make changes for their plans for upcoming lessons.

5.3 Methods for assessing inquiry in class

In class, it is mainly teachers who assess learners' inquiry competencies. But assessment does not necessarily have to be performed by the teacher. Indeed, other learners in the class can also give feedback through peer-assessments and learners themselves can evaluate their own work in self-assessments.

5.3.1 Assessments by the teacher

Teachers assess learner performance in different ways. Sometimes it happens by chance when a teacher observes something in class that demands a reaction. On the other hand, assessment can be planned, for example if a teacher prepares tasks or requires reports of their learners. In this section, various methods of assessment by the teacher are introduced.

- ***Observations***

  The most common form of assessment is observation. Often, observations are made unconsciously, alongside other tasks, and are not systemically recorded (on-the-fly observations). On the other hand, observation can also be used as an explicit method of assessment.

  On-the-fly observations

  On-the-fly observations are an example of informal formative assessments. The term "on-the-fly" describes observations that happen as a part of regular classroom activities in a short timeframe. It entails teachers' quick, spontaneous judgements and actions based on information gained from the learners through various means. This information can come from learners' self-contributions, but often teacher questioning is a way to prompt learner knowledge. Questions best suited for on-the-fly formative assessment are open-ended and tap into diverse types of knowledge, including procedural and strategic knowledge (Ruiz-Primo, 2011).

  After the information about learners' knowledge has been gained, it needs to be interpreted and judged. Usually, this is done by the teacher, but sometimes learners' peers can act as interpreters as well (ibid.). Past research has distinguished between two different orientations teachers can have for interpreting evidence. Certain teachers have an evaluative orientation whereby they are "listening *for*" a specific idea or explanation from the learners, while other teachers might have an interpretive orientation where they "listen *to*" the learner and try to understand and make sense of the learners' ideas and explanations (Davis, 1997; Talanquer et al., 2015). For the judgements to be based on evidence about the learners' actual achievement, teachers should strive for the latter orientation. Finally, the teacher must react to the information. This can happen through offering explanations, comparing learners' ideas, or providing feedback (Ruiz-Primo, 2011).

Systematic classroom observations

Systematic classroom observations are valuable tools in the assessment of learners' competencies (O'Leary, 2020; Schermer & Fosker, 2020). They can be used for formative and summative assessments equally. To use observation as an explicit method of assessment, they must be deliberately planned and designed. The following key questions must be considered in advance:

- Who should be observed?
- Who should observe whom?
- What should be observed?
- How should the observation be done?
- When, for how long, and how often should observation take place?
- How should findings be recorded?
- What should be done with the findings?

The monitoring of learners' performances in lessons is particularly necessary when learners work on practical tasks autonomously, alone or in groups, which is often the case during inquiry-based learning. Observations of behavior can concern a single learner or focus on interactions among several learners in a group.

Observing things during class explicitly needs time, which is scarce in day-to-day teaching. So, it is even more beneficial to bear in mind that not all observations must be made by the teacher themselves. Learners are usually very capable of observing each other if the work assignment and the documentation are clearly specified (Panadero & Brown, 2016). Observations must be documented. The most common form of documentation is the written record. Depending on what is being observed, qualitative or quantitative data are gathered. It is of course possible to document observations in the form of a continuous text. However, it usually saves time when an observation grid is available, on which the things which are to be observed are assessed on a scale, via symbols, or with short written comments.

Example 5.2

The following example items could be part of an observation grid

	competency is achieved	competency is partly achieved	competency is not achieved
The learner can ask research questions.			
The learner can formulate hypotheses.			
The learner can name dependent and independent variables.			
The learner can apply a variable-control strategy.			

- ***Oral methods***

  Being able to explain things properly is a fundamental ability learners should acquire from science teaching. If teachers often engage in oral kinds of assessment, learners are trained in the competency of explaining scientific issues on-the-spot. Besides, oral methods of assessment develop communication skills, offer the possibility to assess deeper levels of learners' understanding, and enable immediate feedback (Hazen, 2020). Just like observations, oral assessment can also be used quite spontaneously for formative assessment or in a planned way for formative and summative assessment. In class, a typical oral method is the dialogue between teacher and learners. It offers the possibility for teachers to get a clearer picture about learners' conceptions. So, it is necessary for the teacher to ask open-ended questions, to listen to the learners carefully, and to challenge learners' ideas.

  Planned oral assessments include oral exams in addition to presentations. For inquiry-based learning, presentations give the opportunity for individual learners or groups to introduce their ideas to the class and therefore enable communication and discussion. Presentations can also include short videos, drawings, sketches, or products from the experimentation process.

- ***Written methods***

  Written methods are quite familiar to teachers in assessing learners' competencies. Of course, written methods cannot be used for assessing all inquiry competencies, but for some they can be a good, time-saving instrument of assessment.

  Written tasks can be used to assess scientific competencies with sensitivity and time-efficiency in some areas related to the following inquiry competencies:

  - selection or autonomous formulation of a question on which a given example study is based;
  - assessment of whether a given problem can be investigated by using scientific methods;
  - selection and autonomous formulation of possible hypotheses for a given example study;
  - selection of variables that must be varied or kept constant in an investigation to answer a question (variable control);
  - selection or formulation of an experiment design for a given question/problem;
  - evaluation of the scientific approach to experiment design, identification of errors in the design, and suggestions for improvement;
  - selection of suitable measuring instruments to answer questions;
  - reading measured data in a simulation (scales, measured values, units);
  - evaluation of hypotheses based on given data or on data obtained in an interactive simulation.

Single steps of scientific knowledge gain can – except for the concrete implementation of an investigation or experiment – be assessed well in a written format. However, it must be noted that correct planning of an investigation does not guarantee correct implementation. Nevertheless, it is not possible to fully incorporate the whole process of inquiry-based learning, starting with the formulation of a question and ending with the discussion on the findings, in a written format. Therefore, written tasks are used to assess and train single competencies in the process of gaining inquiry competencies. This provides an essential service for identifying and eliminating frequent sources of error during the individual investigation steps. To develop a scientific mindset and the understanding of the inquiry process, it is necessary to go through the complete circle of inquiry, even repeatedly.

In general, several formats of written tasks can be used:

- single-choice tasks, where a correct answer must be selected;
- complex-choice tasks, where several answers are added to a total score;
- numbering and sorting tasks, where learners have to arrange essential points in a correct order;
- gap-fills and banked gap-fills, where learners complete small pieces of information;
- open questions, where learners formulate their answer as a text.

▪ ***Assessing learners' performance through work samples***

A good possibility for assessing learners' performance is the assessment of work samples that learners prepare during the inquiry process. Compared to written methods like tests or worksheets, work samples allow the capture of the whole inquiry-based learning process. A very common example is the analysis of experimental reports, which follow the inquiry circle, from asking questions, through expressing hypotheses and planning the experiment, to describing the experiment itself and its results, and drawing conclusions (Nybo & May, 2015). Experimental records can be used in an open format, where learners have to write the whole report by themselves – a process that is quite demanding. Easier is the use of worksheets, which guide the learners through the inquiry process. For differentiation, various parts of the inquiry process can be readily prepared on the worksheet. An alternative to written records can be video records, which are especially useful during the execution of the experiment itself. Videos can be easily made using learners' smartphones, if video recorders are not at hand. Another possibility of work examples are portfolios (Vitale & Romance, 2005). Portfolios allow the collection of samples of a learner's work. For formative assessment, portfolio assembly must be supported by the teacher, so the competency development can be tracked. For summative assessment, the portfolio and its presentation can also be used. Portfolios can be grouped into course portfolios, process portfolios, and product portfolios (Stern, 2010).

Course portfolios include a collection of materials for one course, one project, or a school subject. The learners may choose their materials on their own while the teacher accompanies the creation process and gives formative feedback. Product portfolios collect a learner’s best work examples and can be used – besides for summative assessment in a given teaching subject – also for external applications for an employment or university prospects. Process portfolios collect work examples including all corrections and supplements. These portfolios show a learner’s development and may act as a template for a course portfolio or product portfolio.

In natural sciences, portfolios can include a collection of tasks and assignments the learners have to do in the classroom, for example laboratory reports or collections of viewing materials, such as herb samples. Another example of a portfolio in natural sciences is the documentation of an oral presentation. The learners can collect the materials, literature, photos and videos in conjunction with peer and self-feedback for their projects.

5.3.2 Self-assessment

The goals of formative assessment include, among others, the reinforcement of learners’ self-competence and their self-responsibility for the learning process. To reach these goals, self-assessment may also be appropriate. Self-assessment can be used for the assessment of social, practical, and academic competencies as well as for aspects of self-concept. Learner self-assessment involves a variety of mechanisms, methods, and techniques which learners use to assess and assign their learning processes and/or products (Panadero et al., 2016).

In general, the correlation between self-assessment and assessment by another person is moderate (Zell & Krizan, 2014). Other results show that the correlation between female learners’ self-assessments and their teachers’ assessment is higher than in the case of male learners and teachers (Roos et al., 2016). Schreiber et al. (2016) investigated the ability of learners to assess their own experimental skills in physics, finding that the possibility of self-assessment accuracy is on average quite high, but also that there are individual differences between learners. To sum up, self-assessment appears to play an important role in academic success and self-regulatory competencies (Panadero et al., 2016). Therefore, self-assessment may be a practical and fast way for teachers to get feedback and for learners to reflect on their learning process.

Teachers need to prepare self-assessment offers and learners need to practise how to evaluate their competencies. It is necessary that the teacher guides, accompanies and analyses the self-assessment (Buholzer et al., 2020).

Methods for self-assessment

The most popular mode of self-assessment, which is also fast, is an evaluation sheet – for instance, with a checklist – where the learners can mark their tasks regarding the competencies they need to acquire in the lesson setting (Buholzer et al., 2020).

Example 5.3

The following items can be used in a self-evaluation sheet:

How did you cope with the work?
Did you complete the tasks in the allotted time?
Did you achieve the stated learning goals?
How did you cope with the related materials?
How well were you able to complete the individual work?
How well were you able to complete the partner or group work?
How difficult was the work assignment for you?
How well did you like the work assignment?
Would you have liked to have had more choice in the assignments?
What would you change about the assignment and why?

Here, it is important that the teacher discloses the learning goals and how to reach them. This can be done with a prepared numbered scale or, for younger learners, with smileys, for example. More time-consuming methods can also raise problems or specificities regarding the task or exercises. Here also, teachers can work with prepared scales – for older learners, open formats are recommended. "Learning journals" can help the learners reflect on their learning process over a short or long period. Learners need to note down how they develop their work. In most cases, learning journals use an open format with diary-type characters. The application of digital tools for self-assessment may support teachers during evaluation. This includes online self-assessment tools in addition to programmed or standardized questionnaires. As well as individual feedback, self-assessment enables quick and easy in-class analysis.

5.3.3 Peer assessment

Definition

A common definition for peer assessment describes it as "an arrangement in which individuals consider the amount, level, value, worth, quality, or success of the products or outcomes of learning of their peers of similar status" (Topping, 1998, p. 250). Peer assessment can focus on various products or outputs, such as written work, oral presentations, or artefacts and it can be used for formative or summative purposes. Although formative and qualitative peer feedback is more cognitively demanding for the assessor, it is more socially comfortable and useful for the assessee in comparison to summative “marks” or “grades" (Topping, 2005). The aim of formative peer assessment is to help peers to identify the strengths and weaknesses of their work and provide suggestions for how to improve it. Further, peer assessment can be one-way or two-way (reciprocal). In the former, learners undertake the role of either assessor or assessee. The latter – reciprocal peer assessment – is more commonly used, since learners can benefit from both roles. These benefits of each role will be discussed later.

The need for peer assessment

Most research concerning peer assessment has been conducted in the context of higher education (van Zundert et al., 2010), but more recent studies have also focused on peer assessment in secondary science education (e.g., Ketonen et al., 2020a; Tsivitanidou et al., 2018). Results show that peer assessment can have many positive impacts on learning processes and outcomes, social interaction, and metacognitive skills (Broadfoot et al., 2013; Topping, 2009). On the other hand, many challenges have been reported as well. For example, if numerical scales are used for rating peer performances, learners may “friendship mark” (Broadfoot et al., 2013) or “bargain” about rates (Ketonen et al., 2020b). Further, learners may avoid criticism, reject feedback, and mock others’ work (ibid.). In addition, learners can be anxious about their ability to assess other’s work or others’ ability to assess their own work (Broadfoot et al., 2013; Sluijsmans, 2002). Despite possible challenges, practicing peer assessment in classrooms has been seen as useful for learners. For example, the Finnish National Agency for Education states that primary and lower secondary learners (grades 1–9; 7–15 years old) must be assessed formatively and summatively. This formative assessment includes self-assessment and peer feedback that does not affect learners’ grades. Giving and receiving peer feedback is practiced under teacher guidance in all subjects (Finnish National Agency for Education, 2020). Further, there is a lot of research-based knowledge on how to successfully implement peer assessment in classrooms, thus responding to these challenges.

Reciprocal formative peer assessment

When assessment is formative, learners have an opportunity to get feedback, which helps them in their ongoing learning process (Black & Wiliam, 2009). In the case of peer assessment, this means 1) learners work on some activity (e.g., an inquiry-based investigation) that produces an output; 2) they get peer feedback on the output; and 3) they can then revise their output. Further, in reciprocal peer assessment learners act in both roles of assessor and assessee. Naturally, peer assessment can be exercised by an individual, a pair, or a small group. For example, in a “Mars rover” project (Ketonen et al., 2020a) learners designed a moving vehicle, measured its velocity, and produced a report about their investigation. Since the peer assessment was reciprocal and formative, each group in the class had an assessor role when they assessed a report by some other group and an assessee role when they received feedback on their own report. After feedback they had an opportunity to revise their report.

Table 5.1: An example rubric for peer feedback in the "Mars rover" technology project (Ketonen et al., 2020a)

Criteria	***Meeting the criteria***			***Written comment***
	Lacking	Partly done	Everything is OK	What was good? What could be improved and how?
A research plan and equipment have been clearly presented.				
Measurements are reasonable and clearly presented.				
The report shows how velocity is calculated from measurements. The calculation includes an equation, numbers, and units.				
Error of measurements and results have been commented on.				

In the assessor role, learners need to practice three assessment skills, which are 1) defining assessment criteria; 2) judging performance; and 3) providing feedback (Sluijsmans, 2002). The first skill requires learners to consider the demands of the task and how success can be measured in order to define their own criteria. However, with young learners who are novices in peer assessment, it is reasonable to start with criteria provided by the teacher. In that case, the skill relates to understanding assessment criteria. Usually, criteria are provided in the form of rubrics (see an example in Table 5.1), which helps assessors in their work and increases the reliability and validity, as perceived by the teacher, of peer assessment (Panadero et al., 2013). The second skill, judging, means learners must be able to compare the peers' work to the criteria and identify its strengths and weaknesses. The third skill refers to learners' ability to give constructive feedback based on their judgement, which helps peers to improve their work.

The second role in reciprocal peer assessment is the role of assessee. It may seem to be an easier role, but many skills are nonetheless needed because learners must be able to critically review the feedback they receive, to make decisions about its usefulness and, if appropriate, how to use it to improve their work. These assessee skills have been described in the framework of feedback literacy (Carless & Boud,

2018) as appreciating feedback, judging feedback, managing affect, and acting on feedback. Table 5.2 summarizes the skills that learners need and that they have an opportunity to practice when reciprocal peer assessment is exercised.

Table 5.2: Overview of learner skills in reciprocal peer assessment (adapted from Carless & Boud, 2018; Sluijsmans, 2002)

Assessor	Assessee
▪ Using (or defining) assessment criteria ▪ Judging ▪ Providing feedback	▪ Appreciating feedback ▪ Judging feedback ▪ Managing affect ▪ Acting on feedback

In summary, there are many reasons why the use of reciprocal peer assessment is beneficial for learning in secondary science. In the assessor role, learners practice certain assessment skills (Table 5.2) and they are cognitively challenged during these actions (e.g., by being asked what the characteristics of a good piece of work are). They also have an extra opportunity to self-assess their own work when they see and review peers' work (Grob et al., 2014). Similarly, in the role of assessee, learners need to practice feedback literacy skills (Carless & Boud, 2018; Ketonen et al., 2020c) and they are cognitively challenged by these demands (e.g., filtering peer feedback; Grob et al., 2014). In addition, peer feedback is a useful addition to teacher feedback because learners get feedback from peers who share the same language, who are working with the same learning process and who are struggling with the same difficulties (Grob et al., 2014). So, this may create fertile ground where the language and problems are easier to share and understand compared to the teacher-learner interaction.

5.4 Validity and reliability of assessment

The quality of assessment is often described using two concepts: validity and reliability.

The validity of assessment describes how well that which is being assessed corresponds to what is meant to be assessed (Dolin et al., 2018). An example of poor validity could be using only verbal assignments to assess learners' skills in scientific inquiry. Verbal assignments require the learners to have good verbal skills, so the assessment of learners' skills in scientific inquiry through these sorts of assignments assesses learners' verbal skills as well. So, using multiple assessment methods diminishes the risk of poor assessment validity.

The reliability of assessment describes how consistent or accurate an assessment it for its use purpose (ibid.). Different assessment purposes have different reliability needs. Large-scale, high-stakes assessment, such as matriculation exams, are tested for reliability because decisions with important consequences are made based on their results. In formative assessment, reliability matters less because formative assessment is based on making judgements and decisions for individual learners or small learner groups with the aim of promoting learning rather than providing each learner with a repeatable and equal assessment. In summative assessment, the crucial point is that, based on similar evidence, similar judgements are made. As we discuss in the next part of this chapter, the option of using the same evidence for learning both formatively and summatively sets its own requirements for the reliability of judgement.

5.5 Combining summative and formative assessment

Figure 5.1 (adapted from Dolin et al., 2018) showcases how summative and formative assessment can be connected. Even though the figure neatly combines these two approaches to assessment, there are some key differences that should be kept in mind.

(1) Summative assessment judgements should be based on the learning goals the learners should have achieved by the time of assessment. These are medium-term goals over a period of a course or a school term. On the other hand, formative assessment judgements should relate to the goals of the lesson or activity at hand, that is short-term goals.

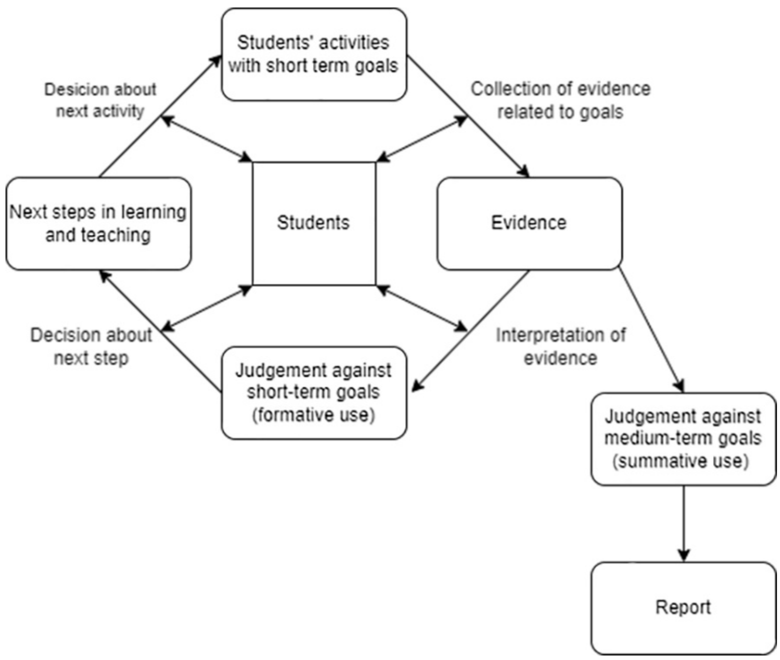

Fig. 5.1: The connection between formative and summative uses of assessment (adapted from Dolin et al., 2018)

(2) While the same evidence can be used for summative and formative assessment purposes, summative assessment judgements should be based solely on the evidence collected, while

formative assessment judgements might differ from learner to learner. In other words, summative assessment should not be based on what sort of feedback a learner received (i.e., decision based on a judgement) but instead on what was the reason for giving that feedback in the first place (i.e., the evidence).

Example 5.4

The learners' goal for the lesson should be to design an experiment which they can use to determine the relationship between two independent variables (for example: battery voltage and number of light bulbs connected in series) and one dependent variable (light bulb brightness). The teacher observes the learners' as they work on the experiment design (i.e., collects evidence). In formative fashion, the teacher makes judgements on the learners' actions and whether they appear to be fulfilling the lesson-level goal. The teacher also collects the learners' plans for the experiment design in written form and uses these plans to make a judgement against one of the course learning goals: "Learners are able to design experiments containing independent and dependent variables". After the lesson, the teacher deduces from their observations that the learners still need to practise experiment design. Thus, they plan the next steps: the next lesson, where the learners will continue practising experiment design.

5.6 Formal and informal formative assessment

As alluded to in the previous part of this chapter, assessment can also be seen as either formal or informal. Formative assessment is called "formal" if it is planned in advance; formal formative assessment often includes some written elements (Bell & Cowie, 2001; Dolin et al., 2018) but other modalities are possible as well.

An example of formal formative assessment might be a short written test prepared by the teacher that is administered to a class as part of normal class work. The goal of the test would be to provide written feedback to the learners and information about the learners' progress for the teacher, which can then affect the teaching plans (Dolin et al., 2018). Compared to this, informal formative assessment is something that happens on-the-fly without planning, for instance when the teacher is going around the classroom and happens to hear a discussion between two learners, which then prompts the teacher to provide feedback to the learners based on their ideas (Shavelson et al., 2008). Most of what teachers do in the classroom can be seen as potential opportunities to provide informal formative assessment to their learners (Ruiz-Primo, 2011).

Both formal and informal formative assessment have their advantages and disadvantages. The advantages of formal formative assessment include the fact that it often provides the teacher with concrete evidence of their learners' progress, which can then also be used in a summative fashion (see the previous part of this chapter). If evidence is used for both formative and summative assessment, teachers should make this clear to their learners in the spirit of transparency. The disadvantages include the fact that if formal formative assessment is limited to just written evidence of learning, other modes that the learners can use to express themselves, such as speech and actions, are left out. This ability to capture learning through multiple modalities is one of the advantages when using informal formative assessment. These modalities include verbal, written, graphic (e.g., drawings), practical (e.g., practical work), and non-verbal (e.g., body language) modes (Ruiz-Primo, 2011). Another advantage is that all instructional dialogue between the teacher and the learners or among the learners is an opportunity for informal formative assessment if they are seen as possible ways for the teacher to acquire information from the learners, make judgements based on it, and use it to guide the next steps in teaching (ibid.). One disadvantage of informal formative assessment is that no evidence is left behind for later use (possibly in a summative fashion) without the teacher explicitly making an effort for this.

Summary

Assessment can be used to evaluate performance (summative assessment), or to promote performance (formative assessment). A combination of both is also possible. If assessment is performed by the teacher, various methods are available: observations, conversations, tasks, analysis of texts or work samples. Assessment can also be carried out by other learners and self-assessment is also a valuable method for teaching.

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6 The Differentiation Tool for inquiry-based learning

6.1 Introduction

Inquiry-based learning (IBL) involves complex processes for learners, such as formulating hypotheses, designing valid experiments, collecting and analysing data, and drawing conclusions (Abd-El-Khalick et al., 2004; Chen et al., 2018; Kirschner et al., 2006; Krajcik et al., 1998). Chapter 3, *Inquiry-based learning,* deals with why IBL should be used in teaching and learning science. However, if IBL is to be implemented in schools well, differentiation and scaffolding in relation to IBL must also be considered (see also Chapter 2 *Differentiation and scaffolding*). It is well-known among researchers and educators that effective IBL relies strongly on proper guidance (Alfieri et al., 2011; Hmelo-Silver et al., 2007; Quintana et al., 2004). With minimal or no guidance, learners will not master IBL competencies (Kirschner et al., 2006). At the same time, guidance must not undermine the open-endedness of inquiry and must be tailored to learners' needs and abilities. Therefore, it is crucial to scaffold learners to accomplish complex inquiry processes and guide them to master these processes so that the scaffolding can be faded out. In this chapter, we present a differentiation concept with a focus on the complex processes of IBL and we introduce five levels of decision-making that will foster differentiation in IBL. For differentiation in IBL, the lesson's domain of focus must first be determined (see Sub-chapter 6.2). This leads to the crucial sub-phases that should be offered in a learner-centered format, and to four differentiation decisions. After the decision about the form of the setting ((1) *grouping decision*),

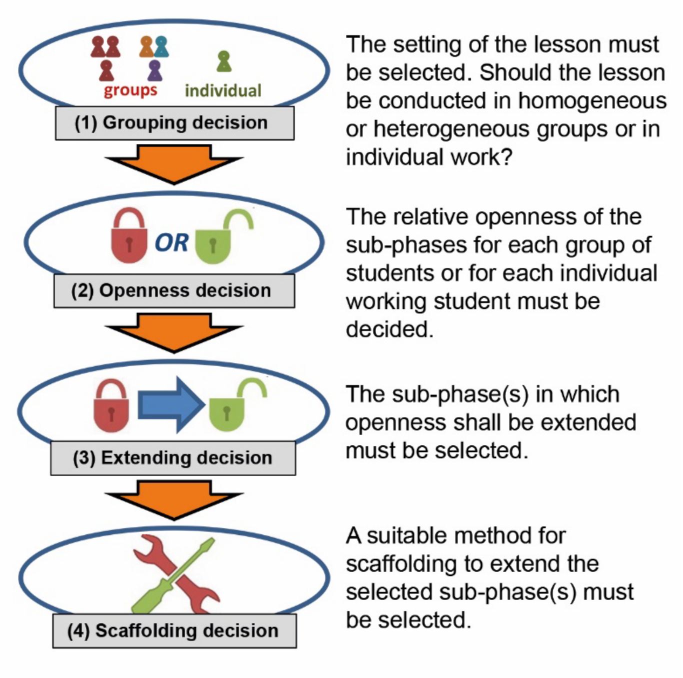


Fig. 6.1: Differentiation Tool; see more in Sub-chapter 6.3

decisions about differentiation in performance ((2) *openness decision*; (3) *extending decision*) in the sub-phases and about scaffolding ((4) scaffolding decision) must follow (see Fig. 6.1 and section 6.3).

6.2 Determination of the objective (domain) of the lesson

As explained in Chapter 3, *Inquiry-based learning*, scientific knowledge can be divided into four domains: procedural, conceptual, epistemic, and social (cf. Duschl, 2008; Furtak et al., 2012; Van Uum et al., 2016). Each domain focuses on teaching, learning and performing different sub-phases of the IBL cycle to varying degrees. The teacher first selects the domain to focus on prior to the lesson to be planned. In the long term, it is crucial to cover all domains, but in any given lesson it is useful to bring only one domain into focus. Focusing on a single domain does not constitute prioritization; rather, it is necessary to set an achievable set of teaching objectives. The domains will always be superimposed – for example, IBL can be used to learn a new context (conceptual domain), but in the same learning process inquiry competencies might be necessary and may need to be improved (procedural domain). Now, the teacher can choose which occupies more space in the lesson: the discussion and deepening the understanding of the content, or discussion and deepening the understanding of the inquiry process. It is usually not possible to achieve both at the same time and with the same depth. If a domain is to be supported in a targeted manner with experimentation in the context of IBL, a decision must first be made accordingly. As already mentioned, the focus on the four domains should be as balanced as possible across the whole set of lessons.

Procedural domain:

The procedural domain refers to competencies for the application of investigative methods (heuristics). Investigation methods involve asking scientifically oriented questions, designing experiments, executing procedures and creating representations of data (Furtak et al., 2012). Therefore, the sub-phases *Orientation*, *Questioning*, *Hypothesis Generation*, *Planning and Conducting Investigation*, *Data Interpretation*, and *Conclusion* must be included explicitly in the inquiry process (see Figure 6.2). If the learners do not have sufficient competencies, these sub-phases should not only be included, but also explicitly explained and developed. The two other sub-phases (*Communication* and *Reflection*) can be addressed in a less explicit way in view of this domain. To develop competencies in the procedural domain for each focused sub-phase, differentiation and scaffolding are necessary. In our opinion, the sub-phases *Communication* and *Reflection* can be helpful for the learning process but are not essential for this domain. In line with the domain's objectives, learners must learn to formulate research questions, generate hypotheses, plan investigations, handle laboratory equipment and draw conclusions.

		Procedural domain	*Conceptual domain*	*Epistemic domain*	*Social domain*
	Orientation	[+]	[+]	[-]	[-]
Conceptualization	Questioning	[+]	[-]	[-]	[-]
	Hypothesis Generation	[+]	[-]	[-]	[-]
Investigation	Planning and Conducting Investigation	[+]	[-]	[-]	[-]
	Data Interpretation	[+]	[-]	[-]	[-]
	Conclusion	[+]	[+]	[-]	[-]
Discussion	Communication	[-]	[-]	[+]	[+]
	Reflection	[-]	[-]	[+]	[+]

Fig. 6.2: Weighting of sub-phases in the different domains; [+]: relatively more teaching time needed; [-]: relatively less teaching time needed

Conceptual domain:

The conceptual domain refers to the knowledge of natural systems and phenomena. Knowledge of natural systems and phenomena (facts, theories, and principles of science) are expected results that will be developed in science teaching and learning (Furtak et al., 2012). Competencies related to *Questioning*, *Hypothesis Generation*, *Planning and Conducting Investigation* and *Data Interpretation* are not central competencies in the conceptual domain. The Figure 6.2 shows the sub-phases that can foster the conceptual domain. At the heart of the conceptual view are the sub-phases *Orientation* and *Conclusion*. In the *Orientation* sub-phase, learners familiarize themselves with the phenomena, while in the *Conclusion* sub-phase, new insights or conceptual changes arise. All other sub-phases that are not priority sub-phases of the conceptual domain are shown in gray color (Figure 6.2).

Epistemic domain:

The epistemic domain refers to the "nature of science". The focus is to teach and learn how scientific knowledge is generated, meaning to understand what processes scientists follow to perform their work and how their scientific research findings are validated. Under this focus, findings gathered by the learners' own scientific investigations are essential (Furtak et al., 2012). The K-12 standards for science education in the USA (NRC, 2012) use the term “scientific practices” to emphasize that doing scientific investigations requires not only skills but also knowledge about each practice. In the IBL context, a scientific investigation always starts with a research question and/or a research hypothesis that leads to the phases that follow. What is crucial here is that the methodology for carrying out an investigation may vary. The processes to be followed, however, must be in accordance with the research question, and findings must be consistent with the data collected and be discussed based on what is already known. Another important aspect when fostering the epistemic domain in a lesson is that learners must construct an understanding of how scientific knowledge develops over time and how new data may contradict what was previously known.

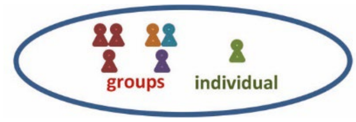
As can be seen from the above, the epistemic domain can fit in all the sub-phases of IBL; however, we believe that it is better to present the epistemic aspect of scientific inquiry in the form of reflection and critical thinking during discussions that take place in the lesson, especially when learners share their research findings. Hence, the sub-phases *Communication* and *Reflection* are the focus of interest in this case (see Figure 6.2) since, according to the inquiry cycle pedagogical framework described in Chapter 3, the processes related to these sub-phases can be integrated into every other phase of the IBL cycle, or at the end of a cycle (see Chapter 3, Figure 3.3).

Social domain:

The social domain refers to collaborative and communicative processes, which are used in the construction of scientific knowledge (Furtak et al., 2012). As mentioned above, making reference to a particular domain in connection with a given process does not mean that the latter are not required in other domains. This becomes very clear, for example, for cooperation in group working, communication, and discussing inquiry results, which are necessary for constructive learning processes. As mentioned earlier, only a limited number of learning objectives can be achieved in a single lesson. The different domains indicate the direction of the learning objectives for fostering competencies that are the focus of the lesson. The social domain includes learning objectives for fostering competencies related to critical thinking and review (of one’s own work and the work of others) as well as competencies for the exchange of findings and work in groups. Learning, in a constructivist view, is an active and social process (Walker, 2015). “Active” means that learners construct knowledge on their own (Schnotz, 2011). The process is also social because learners should also adopt a different perspective to observe gaps, flaws, difficulties in their own learning, and to open up new, creative paths (Neubert et al., 2001). Collaboration and communication offer possibilities to adopt just such a different perspective. So, the focus when promoting the social domain is on the sub-phases *Communication* and *Reflection* (see Figure 6.2).

6.3 Differentiation Tool

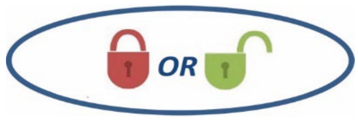
After deciding which domain to focus on in the lesson, decisions on differentiation must be made. There are four stages in the process of planning differentiation in which to decide: (1) the selection of the setting; (2) the selection of the possible openness of the sub-phases; (3) selection of sub-phases which should be scaffolded to the next level of openness; (4) the selection of methods for scaffolding. All those decisions are based on pre-assessment of learners' knowledge and skills which is described in more detail in the section 6.4.



(1) Selection of setting

The intended setting of the lesson must be selected. Should the lesson be conducted in homogeneous or heterogeneous groups or should learners work individually?

Concerning the different sub-phases, learners in a class tend to be very different in their competencies. Now the first decision must be taken: to group learners with similar competencies (homogeneous groups), to build heterogeneous groups, or to let the learners work individually. In the case of learners working individually, they can seek to achieve either the same learning objective or different learning objectives. In contrast to individual work, social aspects are highlighted in group work. Learners need to work together and exchange ideas when planning, implementing and evaluating their work. In heterogeneous groups, learners with higher performance can coach learners with lower performance. The advantage of homogeneous groups is the opportunity to give tasks that have an appropriate level of complexity for all group members (higher and lower achievers). In individual work it is possible to respond to the individual learners' requirements. Each social form offers advantages and disadvantages. Therefore, the best social form must be chosen in terms of class and content.



(2) Selection of the relative openness of the sub-phases

The relative openness of the sub-phases (*Orientation*, *Questioning*, *Hypothesis Generation*…) for each group of learners or for each learner working alone must be decided (openness which the learners or groups are able to handle without help/scaffold). Regardless of whether the first differentiation decision leads to learners working individually or to homogeneous or heterogeneous groups, the next decision for each group and for each sub-phase is what degree of openness is possible. In contrast to deciding on the appropriate degrees of openness for individual learners and homogeneous groups, it is more difficult for heterogeneous groups. In general, there are three ways to determine the appropriate degrees of openness for heterogeneous groups.

- ***Way 1:*** The teacher looks at the skills of the weakest learners and decides the degree of openness according to these. Advantage: no learner will be overwhelmed. Disadvantage: high-performing learners may be underwhelmed.
- ***Way 2:*** The teacher looks at the skills of the high-performing learners and decides the degree of openness according to these. The high-performing learners have the task of acting as mentors and coaching the other learners. Advantage: no learner will be underwhelmed. Disadvantage: there are many tasks for the high-performing learners (mentoring and thinking through the inquiry process). Low-performing learners could be overwhelmed.
- ***Way 3:*** The teacher looks at the skills of the middle-performing learners and decides the degree of openness according to these. The high-performing learners have the task of acting as mentors and coaching the other learners. Advantage: no learner will be underwhelmed and tasks (mentoring and thinking through the inquiry process) are shared between the learners. Disadvantage: low-performing learners could be overwhelmed.

Example 6.1

Phenomenon: Birds spread their feathers further from their bodies in winter. This leads to a thicker film of air between the feathers and therefore better insulation. A research question could be: "Why does a bird spread its feathers further from its body in winter?"

Fig. 6.3: Left picture: robin in summer, The OtherKev, 2020; right picture: robin in winter, Eckehard Jagdmann, 2016. Both pictures are available on Pixabay (license for free commercial use)

When we look at the two sub-steps *Hypothesis Generation* and *Planning and Conducting Investigation* (Experiment) for example, the learners in the different groups can be different in their competencies (for this example, we only look deeper at these two sub-phases). For our example we have two groups and decide that, for group 1, it is possible to formulate hypotheses in an *opene*d form. For group 1, it is possible to formulate a hypothesis with help of word cards (word cards could be “air” and “insulation”). For group 2 we opt for a *moderately opened* form. Group 2 needs help in the form of a pool of hypotheses and the group choose a possible hypothesis (the pool could include the following hypotheses: “A thicker film of air leads to better insulation.”, “Spreading feathers prevents them from being soaked.”, “Spreading feathers is a partner-seeking behavior.”).

We decide that it is possible for group 1 to design an experiment in an *open* form, while for group 2 a *moderately opened* form is necessary (for example: the teacher offers material which the learners use to design an experiment; the material could be: different beakers, two equal portions of feathers, hot water, test tubes and thermometers).

These decisions must also be taken for all other phases. This result in two different patterns for our two example groups (see Figure 6.4).

		0 ***closed***	***1*** ***moderately opened***	***2*** ***opened***	***3*** ***open***
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
Conceptualization	**Hypothesis Generation**	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a hypothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Leiners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
Investigation	**Data Interpretation**	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	Learners develop their own conclusion

Teacher-directedness → Student-directedness

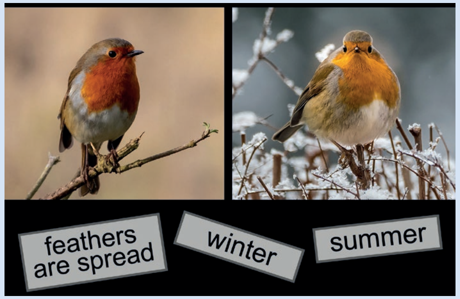
group 1
group 2

Fig. 6.4: Patterns of example groups

There are various methods to support learners in the different degrees of openness. In Table 6.1, we give examples of these methods. Readers should be encouraged and stimulated to consider other appropriate methods. Most methods listed in the table relate to the bird example (Example 6.1) but when this was not possible, we used examples from other contexts.

Table 6.1: Methods to support learners in the different degrees of openness

Sub-phase	Openness	Idea/method
Orientation	***closed***	▪ The teacher describes a phenomenon. Example: "In winter, birds spread their feathers further from their bodies than in summer, so there is more air between the feathers. What could be the reason for this phenomenon?" ▪ Pictures (Figure 6.5) and a short text are given: "In summer, the robin holds its feathers near the body. In winter, the bird looks more ball-shaped, because it fluffs its feathers. So, more air can be trapped between the feathers for better insulation."
	moderately opened	▪ Presentation of a phenomenon (real, with film, with pictures) with given clues (see Figure 6.5 as an example).  Fig. 6.5: Phenomenon with hints Left: robin in summer, The OtherKev, 2020; Right: robin in winter, Eckehard Jagdmann, 2016. Both pictures are available on Pixabay (license for free commercial use); pictures have been adapted ▪ Presentation of a phenomenon (real, with film, with pictures) and word cards. The learners place the correct word cards to the phenomenon (see Figure 6.6 as an example).

		 Fig. 6.6: Phenomenon with word cards Left: robin in summer, The OtherKev, 2020; Right picture: robin in winter, Eckehard Jagdmann, 2016. Both pictures are available on Pixabay (license for free commercial use)
	opened	▪ Presentation of a phenomenon (real, with film, with pictures) with given prompts. Example: What are the differences between the two pictures (Figure 6.3)? ▪ Presentation of real phenomena and an incorrect picture for the phenomena. The learners have the task to find the error(s) in the picture. The teacher shows a film sequence in which different birds can be seen in winter (with puffed-up feathers) and in summer (without puffed-up feathers). After the film, the teacher shows two pictures: one with a bird in winter and one with a bird in summer. Neither bird has puffed-up feathers.
	open	▪ Presentation of a phenomenon in a film. ▪ Presentation of a phenomenon with two pictures (see Figure 6.3 as example). ▪ Learners explore with given materials and find phenomena. For example, in the context of chemistry, learners are allowed to mix white powders (salt, sugar, baking powder, washing powder, citric acid powder) into water. In some trials, foam is created.

Questioning	***closed***	▪ The research question is given by the teacher: “Is it correct that a bird spreads its feathers in winter for better insulation?”
	moderately opened	▪ Learners choose one or several questions from a pool of possible questions. ▪ Learners generate a question with given word cards (all elements needed for generating possible questions are provided).
	opened	▪ Some word cards (e.g., the independent variable and the dependent variable, or only one of them) are offered. Learners use the cards and think about the other words needed to formulate the question. ▪ Learners formulate questions in groups. The teacher discusses with the groups whether the questions are science questions or not and, together with the learners, improves the questions (for an experiment, a causal question is necessary).
	open	▪ Learners ask their own questions. Only if material is lacking are possible questions sorted out by the teacher.
Hypothesis Generation	***closed***	▪ The teacher generates the hypothesis.
	moderately opened	▪ Learners choose one or several hypotheses to test from a pool of hypotheses. ▪ Learners formulate a hypothesis with given word cards (all elements needed for the formulation of possible hypotheses is provided). ▪ Learners get the beginning of a sentence resulting in a hypothesis: “I suppose that…”; “When…, this results in…”; “If…, then…”.
	opened	▪ Some word cards (e.g., the independent variable and the dependent variable or only one of them) are offered. Learners use the cards and think about the other words needed to formulate the hypothesis. ▪ The teacher offers one possible hypothesis and the learners generate others. For example, in the context of botany, the factors for germination should be identified. The teacher offers the hypothesis "Warm temperature is necessary for germination" and encourages learners to find other hypotheses.

	open	▪ Learners formulate possible hypotheses by their own.
Planning and Conducting Experiment	***closed***	▪ The teacher gives clear instructions. ▪ Learners receive a work sheet with a list of materials, a picture or drawing of the experimental setup and the instructions for conducting the experiment. They also get the complete set of materials necessary for the experiment.
	moderately opened	▪ Learners chose from a set of instruction sheets. Each instruction sheet gives all the steps for an experiment. Learners must decide which one fits the hypothesis and is possible to carry out in school. ▪ The teacher offers a set of materials. All materials must be used to design the experiment. *For safety reasons, the teacher must check the learners' experiment plans before they start to work!*
	opened	▪ The teacher offers a set of materials, only some of which are useful or necessary to design the experiment. ▪ The teacher offers only one or some materials (as a starter set). Learners need to think about the other materials. *For safety reasons, the teacher must check the learners' experiment plans before they start to work!*
	open	▪ Learners plan and conduct an experiment without any help. *For safety reasons, the teacher must check the learners' experiment plans before they start to work!*
Data Interpretation	**closed**	▪ The teacher collects the data from the learners and shows how to present them (table, chart, diagram, or other graphical representation). The teacher points out the relationship between variables and explains them to the learners.
	moderately opened	▪ Learners present their experimental observations. Relationships between variables are discussed in a class discussion (strongly led by the teacher). ▪ Learners interpret the data in their groups with a checklist: (1) Does the independent variable have a positive covariation ("If more…, then more…") with the dependent variable? YES/NO; (2) Does the independent variable have a negative covariation

		("If more…, then less…") with the dependent variable? YES/NO; (3) Is it possible to generate a valid conclusion from the experimental observations? YES/NO
	opened	▪ Learners present their experimental observations. Relationships between variables are discussed in a class discussion (mildly led by the teacher). ▪ Learners interpret the data in their groups with prompts: "Does the independent variable have an evident effect or no evident effect on the dependent variable?", "What kind of relationship is there?"
	Open	▪ Learners interpret the data without any help: they choose a graphical representation of the data on their own. They interpret the data, and they show and discuss the relationships between variables.
Conclusion	***Closed***	▪ The teacher draws conclusions. They present a well-formulated sentence or text that summarizes the results of the experiment and includes the answer to the research question. Also, the confirmation or rejection of the hypothesis is given or at least strongly led by the teacher.
	moderately opened	▪ Learners present their first thoughts on the conclusion (if the hypothesis is confirmed, the question is answered). The conclusion is discussed in a class discussion (strongly led by the teacher). ▪ Prompts are given: (1) "If your hypothesis was correct, in which of your experimental trials should you be able to see… and in which not?" (2) "Compare your considerations (answers to prompt 1) with your observations." (3) "Is your hypothesis confirmed or rejected?"
	opened	▪ Learners present their first thoughts on the conclusion (if the hypothesis is confirmed, the question is answered). The conclusion is discussed in a class discussion (mildly led by the teacher). ▪ Learners draw conclusions in their groups, guided by prompts: "Is the hypothesis confirmed?" "Has the question been answered?"

	open	▪ Learners formulate conclusions in their groups without help. They answer the research question and determine whether the hypothesis is confirmed or rejected.
Communication	***closed***	▪ The teacher asks closed questions. Learners answer with yes and no. ▪ Communication is teacher-centered. The role of the learners is to listen and ask questions.
	moderately opened	▪ Learners present their experiment and findings with the help of a given structure for the presentation. ▪ Learners are supervised by older or higher-performing learners while they prepare the presentation.
	opened	▪ Learners present their experiment and findings in a class discussion and the teacher moderates the presentation. ▪ Learners present their experiment and findings in a class discussion and other learners moderate the presentation.
	open	▪ Learners present their experiments and results to others without any help.
Reflection	***closed***	▪ The teacher reflects the experimenting and results.
	moderately opened	▪ Learners use a list of questions for reflection. Example: (1) “Is the question a research question?” (2) “Is the hypothesis an appropriate one?” (3) “Is the control-of-variables strategy used?” (4) “Are there repeated measurements?” (5) “Is the conclusion valid?” ▪ Learners use a checklist for reflection (see Figure 6.7 as an example).

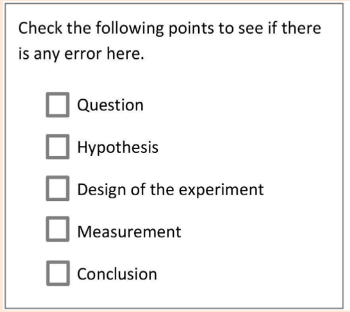
<table>
<tr><td></td><td></td><td>

Fig.6.7: Reflection checklist</td></tr>
<tr><td></td><td>opened</td><td>Learners reflect in a class discussion and the teacher moderates the reflection.
Learners reflect in their work groups. The learners are coached by an older or high-performing learner.</td></tr>
<tr><td></td><td>open</td><td>Learners reflect on their experiments and results without any help.</td></tr>
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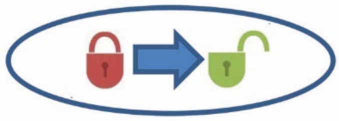
(3) Selection of sub-phases which should be scaffolded to the next degree of openness



Scaffolding is needed to foster learners' competencies to carry out the various sub-phases in a more open form and to help learners to see science as a way to generate knowledge (e.g., Metz, 2004). Competencies to plan and perform experiments are not acquired only by doing (Bell et al., 2003). Exercises and explanations are necessary to develop learners' experimental competencies (Baur et al., 2019). In this sense, first, a decision is required which sub-phase(s) should be addressed for competency expansion. This sub-phase can be different in each group or for each learner. The possible degree of openness of the selected sub-phase in a group or in a single learner (chosen in the second decision, *Selection of the relative openness of the sub-phases*) is then taken to the next degree of openness with the use of scaffolding (see: fourth decision, *Selection of methods for scaffolding*). It seems useful to extend only one or two sub-phases per group. There are two ways to select the sub-phases to be extended in a class.

- ***Way 1:*** Each group (or learners working individually) extends the respective degree of openness and therefore has the opportunity to expand their competencies in the same sub-phase. Advantage: the teacher can concentrate on only one sub-phase in the selection/creation of scaffolds and in the assessment of the learners. Disadvantage: perhaps not all groups (or learners working individually) need an extension in the openness of the selected sub-phase – maybe their work is already open or perhaps they need a much more closed form in the sub-phase.
- ***Way 2:*** The groups extend the degree of openness and therefore have the opportunity to expand their competencies in different sub-phases. Advantage: each group (or learner working individually) can be supported to acquire competencies that are important for the group (or learner working individually). Disadvantage: it can be challenging for a teacher to look at different sub-phases for each group (or learners working individually) and to provide scaffolding for different sub-phases. Joint reflections in the class about different sub-phases can also be very time-consuming and possibly confusing for learners.

Example 6.2

In this example, we think that the experimental content is suitable to extend the competencies of group 1 in generating questions. Our goal is to help the group members to come to an open form of work. In all the other sub-phases, we have decided not to extend the chosen degree of openness. For group 2, we see the experimental content as suitable to improve their competencies in designing an experiment. We have opted for this sub-phase and we decide that this will be the only sub-phase for this group, which will be extended in its degree of openness. We choose Way 2 “The groups extend the degree of openness in different phases” among the two ways explained above.

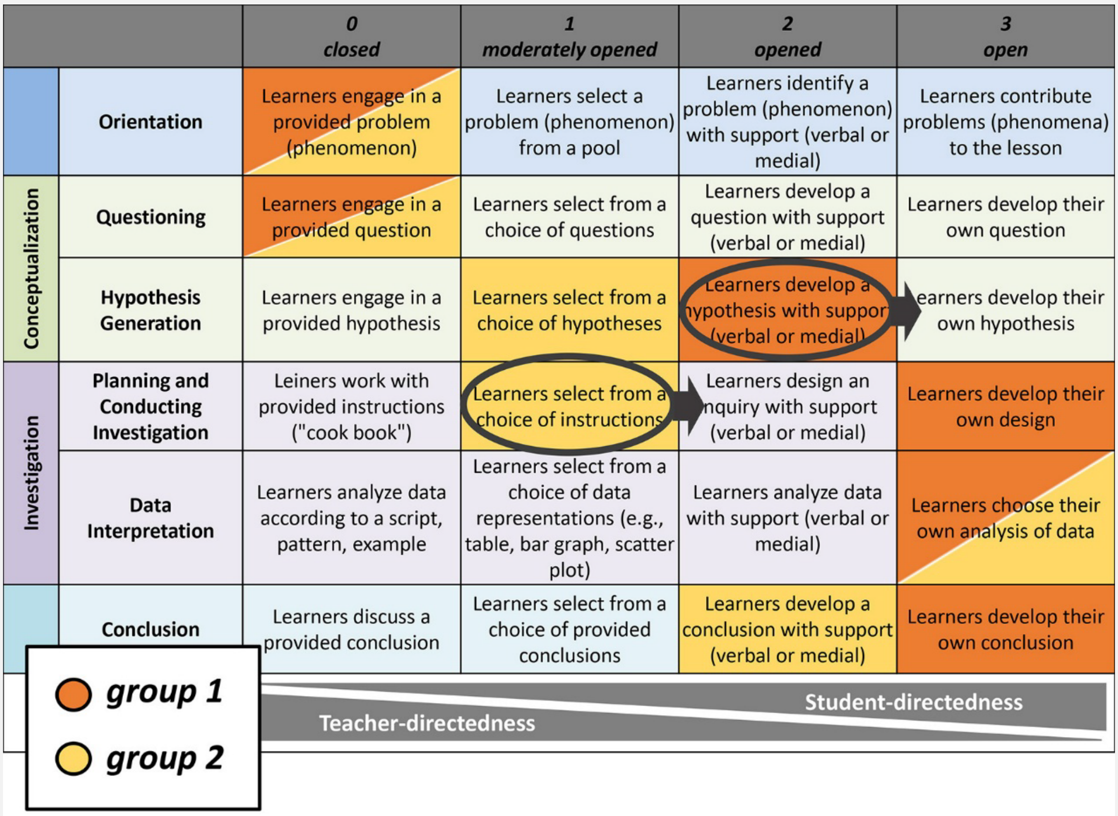


Fig. 6.8: Scaffolding to the next degree of openness

(4) Selection of methods for scaffolding

The final differentiation decision is to select a suitable method for scaffolding to extend the selected sub-phase(s). Providing proper scaffolding during inquiry helps learners overcome their difficulties at first and then allows them to perform the inquiry sub-phases in a more open form. Deciding how much support is to be offered to learners and what is the proper scaffolding method have been highlighted as crucial in inquiry learning by many researchers (Arnold et al., 2014; Koksal & Berberoglou, 2014; Minner et al., 2010). The main challenge when deciding on the scaffolding method is to accommodate between structuring on the one hand and problematizing on the other (Reiser, 2004). Structuring and problematizing are two contrasting mechanisms that need to be placed together in a balanced way to simplify complex inquiry tasks (i.e., structuring), but also increase complexity locally to engage learners in demanding sub-tasks (i.e., problematizing). So, scaffolding methods must be selected very carefully prior to the lesson. However, teachers must be prepared to provide on-the-fly scaffolding to learners according to their needs during the lesson.

In the following table, we list some of the main scaffolding methods as reported in the scientific literature in the relevant field. The methods described in the table are content-independent; however, we provide examples for each, some of which are from the cited scientific articles.

Table 6.2: List of scaffolding methods

Scaffolding method	Description/Example	Reference
Prompts	Prompts are provided in the form of questions or hints that remind learners to carry out certain actions, assignments or learning processes they may overlook (de Jong & Lazonder, 2014). Prompts vary depending on what learning process learners will be supported to complete. Moreover, prompts may be provided orally, in written form, or even in computer-based learning environments. Some examples are provided below: Prompts for hypothesis generation: ▪ Formulate your hypothesis as a possible answer to the research question. ▪ Scientists use the knowledge and information they have collected to make a sophisticated guess about the outcome of their experiments. Can you make a sophisticated guess about the outcome of your experiment? This will be your hypothesis. ▪ A good hypothesis can be formulated in the form of an "If…, then…" statement. Prompts for experimentation: ▪ Before conducting your experiment, make sure that you manipulate all the variables properly. ▪ Is there a test and a control trial in your experiment? ▪ Are all variables that are not examined unvaried?	de Jong & Lazonder (2014)

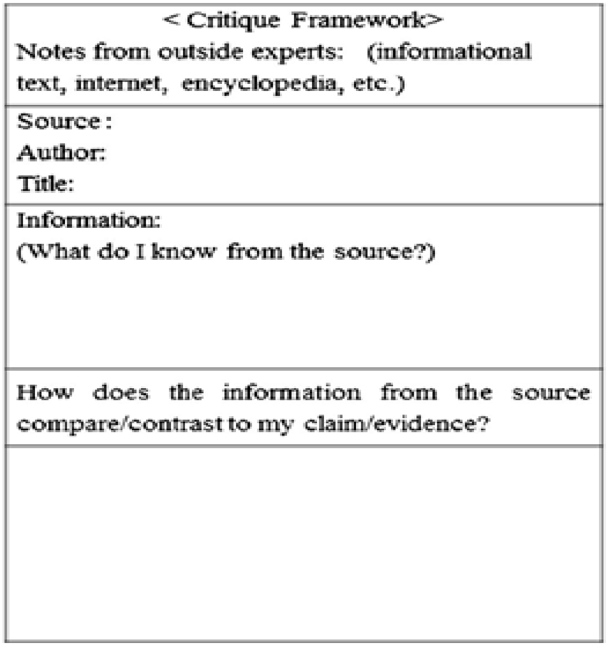
	<u>Prompts for self-reflection</u>: ▪ Did you initially think about the problem and subsequently formulate your hypothesis? ▪ Did you vary one variable at a time? ▪ Did you keep a record of your observations? ▪ Did you have enough evidence to support your conclusion?	
Heuristics	Heuristics are similar to prompts but offer more specific support. In fact, they are defined as suggestions on how to perform an action or learning process (de Jong & Lazonder, 2014). To understand the difference between prompts and heuristics, let us examine an example for hypothesis generation. A prompt could be stated as "A good hypothesis can be formulated in the form of an 'If…, then…' statement" and the respective heuristic in this case can be stated as "Formulate your hypothesis in the form of an 'If…, then…' statement. Include the independent variable after *if* and the dependent variable after *then*". Examples of heuristics during the planning and conducting of experiments: ▪ VOTAT – Vary One Thing At a Time (Tschirgi, 1980). ▪ Extreme values – Try some extreme values to see there are limits on the proposed relationship (Schunn & Anderson, 1999).	de Jong & Lazonder (2014); Tschirgi (1980); Schunn & Anderson (1999)
Science Writing Heuristic (SWH)	The SWH, although it is a type of heuristic, is presented in Table 6.2 as a separate entry since it is a well-developed approach and it provides specific guidance to learners for writing quality inquiry reports. It includes a template for learners, guiding them in writing argument-based inquiry reports and a template for teachers, supporting them in utilizing the SWH in their IBL lessons. The	Hand (2008)

template for learners consists of seven phases and the template for teachers consists of eight phases.

The two templates, as described in Hand (2008, pp. 6-7), are provided below:

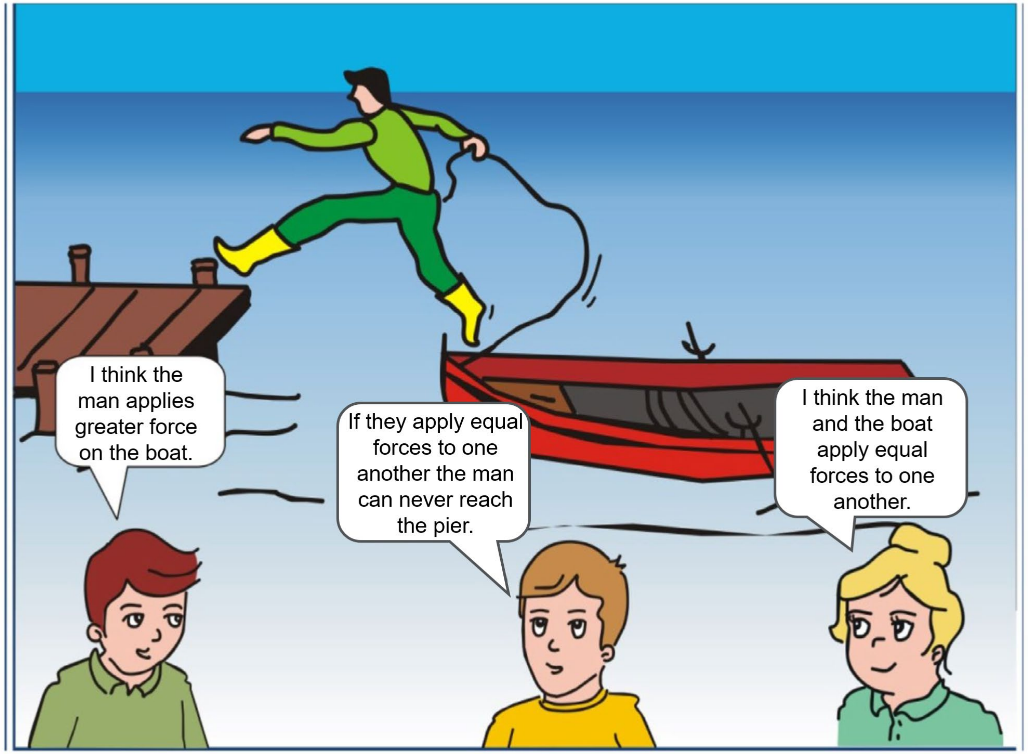
SWH template for teacher	***SWH template for learner***
Phase 1: Exploration of pre-instruction understanding through individual or group concept mapping	Phase 1: Beginning ideas – What are my questions?
Phase 2: Pre-laboratory activities, including informal writing, making observations, brainstorming and posing questions	Phase 2: Tests – What did I do?
Phase 3: Participation in laboratory activity	Phase 3: Observations – What did I see?
Phase 4: Negotiation phase I – writing personal meanings for laboratory activity (e.g., writing journal)	Phase 4: What can I claim?
Phase 5: Negotiation phase II – sharing and comparing data interpretations in small groups (e.g., making group charts)	Phase 5: Evidence – How do I know? Why am I making these claims?
Phase 6: Negotiation phase III – comparing science ideas to textbooks or other printed resources (e.g., writing group notes in response to focus questions)	Phase 6: Reading – How do my ideas compare with other ideas?
Phase 7: Negotiation phase IV – individual reflection and writing (e.g., creating a presentation, such as a poster or report, for a larger audience)	Phase 7: Reflection – How have my ideas changed?

	Phase 8: Exploration of post-instruction understanding through concept mapping The SWH template for learners includes a set of questions to help them construct scientific arguments by making connections among their research questions, experimental designs, observations, data, claims, and evidence. Specifically, learners first write the question that guided their investigation (Phase 1), then they report all the preparations and procedures for conducting their experiment (Phase 2), including the observations they made and the data they collected (Phase 3). Once learners have their data and observations they answer their research question in the form of a scientific claim (Phase 4) and use evidence from their data analysis and interpretations to support their claim (Phase 5). Then, they compare their findings with other findings and ideas, discussing the quality of their work and how strong their claims are based on evidence (Phase 6). Finally, they reflect on their work and explain how their ideas have changed and their understanding has developed (Phase 7).	
Scaffolded Critique Framework (SCF)	The SCF was created to supplement the SWH, presented above, and to better support learners' critical thinking and critique processes. Using the SCF template, learners validate their arguments by recording the sources of the information they collect and by comparing the collected information with their ideas, claims, and evidence. The SCF is considered a specific type of prompt that is incorporated in the sixth phase of the SWH, namely Reading, in which learners compare their own ideas with other ideas from other sources.	Jang & Hand (2017)

	The image on the right shows the SCF template (Jang and Hand, 2017, p. 1219). The recording of information from a specific source is the first stage of the SCF and the second is the comparison of the recorded information with a learner's claim and evidence. This comparison is useful for learners during the writing activity in the sixth phase of the SWH template, since it allows them to analyze, critique, and synthesize several competing ideas when they develop their own arguments.  < Critique Framework> Notes from outside experts: (informational text, internet, encyclopedia, etc.) Source : Author: Title: Information: (What do I know from the source?) How does the information from the source compare/contrast to my claim/evidence? Fig. 6.10: SCF template	
Structuring questions for experimental design	Structuring questions aim to make learners think about the important aspects that they need to take into account when designing an experimental procedure. Questions are given to learners in the form of an assignment and they provide their responses. For example: ▪ How should the dependent variable be measured? ▪ How should the independent variable be varied? ▪ Which variables mut be controlled for?	Arnold et al. (2014)

Hints on how to measure variables	Hints are provided in the form of instructional support (i.e., direct presentation of information) to help learners operationally define the dependent variable, thereby discovering how to measure it. The following example in Arnold et al. (2014, p. 2748) illustrates how this scaffolding method can be used: <u>Research question</u>: "*Is enzyme activity dependent on temperature?*" <u>Information provided in the form of a hint for operationalization</u>: "*The functioning of lipase can be detected if you give them into a fatty liquid like evaporated milk. Then, lipase degrades the fats into fatty acids and glycerin. Because of the resulting fatty acids, the pH value is lowered and the solution gets more acidic. In order to be able to detect differences in pH value the solution should be at pH 11. This can be done using sodium carbonate*".	Arnold et al. (2014)
Step-by-step help cards	Step-by-step help cards are provided to learners to use whenever they need support. They are free to use the help cards offered. The order of the cards is predetermined, as they build on each other. Learners are free to choose how many cards they use. Below is an example from Arnold et al. (2014, p. 2748): The topic is enzyme activity and learners may be given the following step-by step help cards regarding the dependent variable: "*(1) the dependent variable is the factor that is supposed to change according to the independent variable. Think about what the dependent variable is in your case.* *(2) The dependent variable in your case is 'enzyme activity' or 'activity of lipase'. Think about how this dependent variable could be measured.* *(3) Lipase degrades the fat of fatty liquids into fatty acids and glycerin. Because of the fatty acids,*	Arnold et al. (2014); Schmidt-Weigand et al. (2009)

	the pH value of the solution becomes acidic. Think about how you could measure the activity of lipase. *(4) The enzyme activity of lipase can be measured via the pH value. If you put lipase into a fatty liquid, like, for example, evaporated milk, the liquid should get sourer and that change can be measured via pH-indicators*".	
Concept cartoons	Concept cartoons introduce a cognitive conflict to learners and motivate them to better understand concepts and generate their own explanations. In this regard, they can be used in the *Orientation* phase to trigger learners' initial ideas about a topic/phenomenon or in the *Discussion* phase to help learners reflect upon the knowledge gained and construct their own explanations. Moreover, they can be used to promote understanding of procedural knowledge and to support learners in understanding the nature of science. For example, a concept cartoon may introduce an experimental setup or experimental design errors to learners and, so, be used in the *Planning and Conducting Investigation* sub-phase. Figure 6.9 shows an example (Atasoy & Ergin, 2017, p. 72):	Atasoy & Ergin (2017); Keogh & Naylor (1999); Lubben et al. (2001);

	 Fig. 6.9: Concept cartoon A man jumps from a floating boat to the pier. *What do you think? Please justify your answer. Please find similar everyday physics instances and then discuss their similarities with the cartoon.*	
Teacher-based metacognitive scaffolding	At the end of a class period or anytime during the lesson, the teacher asks learners questions about their inquiry tasks. The purpose of these questions is to elicit learner metacognitive abilities. All learners participate in the discussion and reflect on both the questions asked and peers'	Wu & Pederson (2011)

	responses. The teacher does not provide any feedback but encourages learners to evaluate each others' responses. According to Wu and Pedersen (2011, p. 2360) this think-aloud type of reflection activity would benefit all learners to regulate their own learning behavior. For example: ▪ Who wants to provide an answer to the driving question of your task? ▪ Follow-up: Explain your reasoning. ▪ How do you (other peers) evaluate this answer? ▪ Follow-up: What science information can be used to answer this question? ▪ etc.	

The information we presented in Table 6.2 covers only a few scaffolding methods that were found in the respective literature. However, teachers are prompted to draw inspiration from these successful methods and think of new ones, or to combine two or more when they design and execute their IBL lessons.

Example 6.3

To bring group 1 of our example (see Example 6.1 and 6.2) from the degree *opened* to the degree *open* in the sub-phase *Hypothesis Generation*, it is possible to use heuristics and step-by-step help cards for scaffolding.

The *heuristics* could be formulated as follows and could be given to learners as a written text:

(1) Pick out all the possible variables that can be found in the phenomenon. Think of the:
- independent variables (variables that lead to the effect)
- dependent variables (variables that make the effect visible)
- variables to be kept constant.

(2) Formulate your hypothesis using an independent variable and the dependent variable(s).

The *step-by-step help cards* could be as follow:

Help 1: The independent variable is after the word “if” (“If…, then…”).

Help 2: The dependent variable is after the word “then” (“If…, then…”).

Group 2 is supported with scaffolding in the sub-phase *Planning and Conducting Experiment* to come from the degree of openness *moderately opened* to *opened*. For scaffolding, prompts and step-by-step help cards are used.

The *prompts* could be formulated as follow:

Is there a test and a control trial in your experiment?

Are all variables that are not examined constant?

Step-by-step help cards: Help cards with advice on the material (e.g., card 1, 2 …: “The following material is not essential: …”; last card: “Use the following materials for your planning: …”).

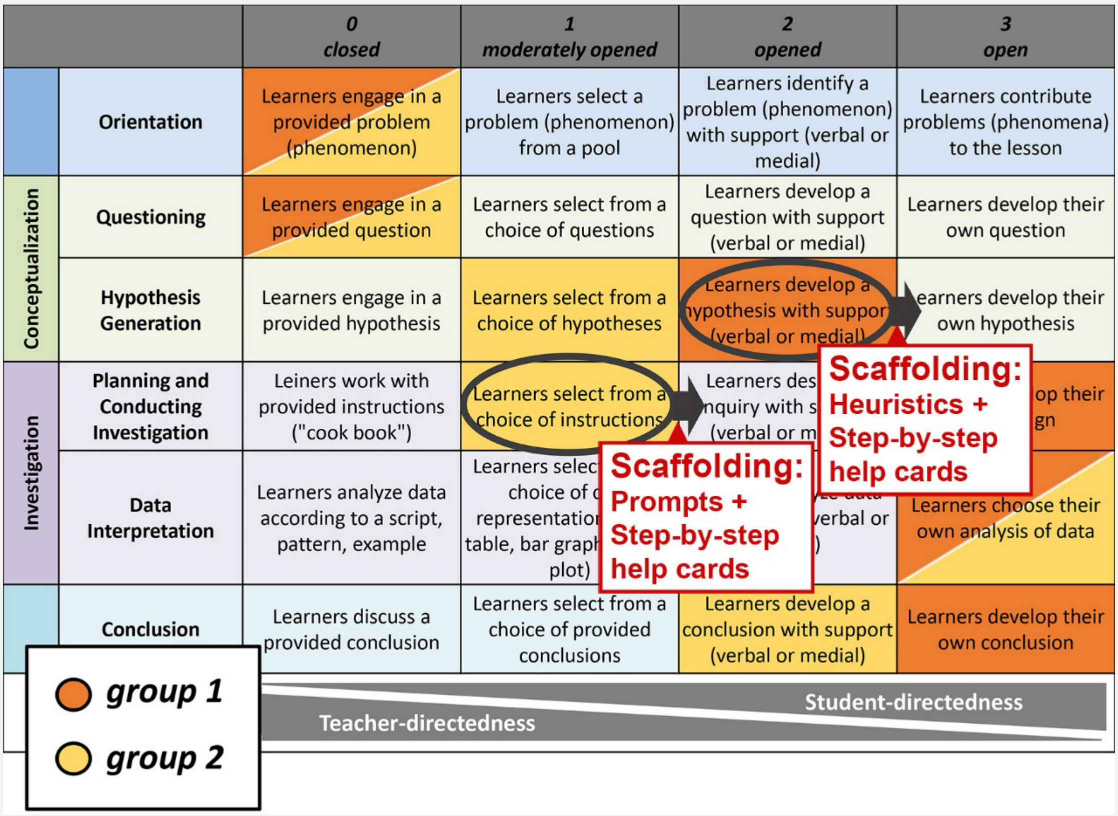


Fig. 6.11: Scaffolding

In addition to these examples of scaffolding methods (Table 6.2), it is worth mentioning the potential for scaffolding that the computer-supported learning environments offer. In such learning environments, the opportunities to incorporate successful scaffolding methods increase because teachers and learners can benefit from software tools, learning analytics, and real-time automatic feedback. Moreover, the number of activities and the level of support provided by utilizing several scaffolding methods can be easily modified before teaching.

Research in the field of computer-supported inquiry learning has shown that, if carefully designed, it can enhance learning through the variety of options that it offers and by increasing the opportunities to monitor learner progress (Alfieri et al., 2011; Slavin et al., 2014; van Joolingen & Zacharia, 2009). However, these learning environments often constitute a great challenge for learners because they entail a high level of cognitive and metacognitive complexity (Azevedo, 2005; Scheiter & Gerjets, 2007). So, in this case, scaffolding has proven to be a promising method for dealing with learners' difficulties and, in fact, its presence in these environments is considered essential (D'Angelo et al., 2014).

Comparing scaffolding provided in a traditional classroom setting and to that given in a computer-supported learning environment reveals an important difference. In a classroom setting, the teacher can make any combination of scaffolding methods for each learner or group of learners, at any time, while scaffolding through a computer must be predefined, limiting the flexibility a teacher has (in this regard, see the classification of the scaffolds into hard and soft scaffolds in Chapter 2, *Differentiation and scaffolding*). However, one could argue that if a computer-supported learning environment is carefully designed and learners can easily monitor their learning progress, then the teacher can spend more time providing real-time, on-the-fly feedback for those who need it. For this reason, we believe that the integration of multiple sources of scaffolding, either from the teacher, from other learning materials (e.g., help cards) or from technology, may increase the effectiveness of each in a complementary way.

All scaffolding methods presented in Table 6.2 can easily be incorporated into a computer-based learning environment. Nowadays, there is a plethora of online Learning Management Systems, which provides tools for authoring and implementing online lessons. In the case of IBL, two popular, open-access learning platforms are widely used by educators all over the world, WISE[1] and Graasp[2]. Both platforms offer authoring features, and users can build their own interactive learning spaces from scratch or adapt existing learning spaces already published on the platform. In particular, a lesson can be enriched with text, video, images, animations, simulations, and learning applications such as a concept map tool, a quiz tool, a graph creation tool, and many more (see Figure 6.12). Moreover, in Graasp, there are also learning applications that scaffold learners in performing specific inquiry learning processes, such as formulating a hypothesis, designing experiments, and drawing conclusions. By taking a closer look at Graasp applications for scaffolding learner inquiry, we see that many of these tools can easily be configured to any content and for the needs of every learner (or group of learners). For example, the Hypothesis Scratchpad tool provides learners with the terms needed for formulating a hypothesis, and learners can drag and drop the predefined conditionals and concepts, from the upper side of the tool, to the space below to create a hypothesis (Figure 6.13). Learners can also type their own words and phrases to use them in their hypothesis. The number of terms given to learners for this inquiry task is a matter of the teacher's choice, based, of course, on learner needs. Moreover, the teacher can predefine the number of hypotheses that learners are expected to formulate by adding empty boxes in the tool, and they can provide a predefined or partially formulated hypothesis.

[1] https://wise.berkeley.edu
[2] https://graasp.org

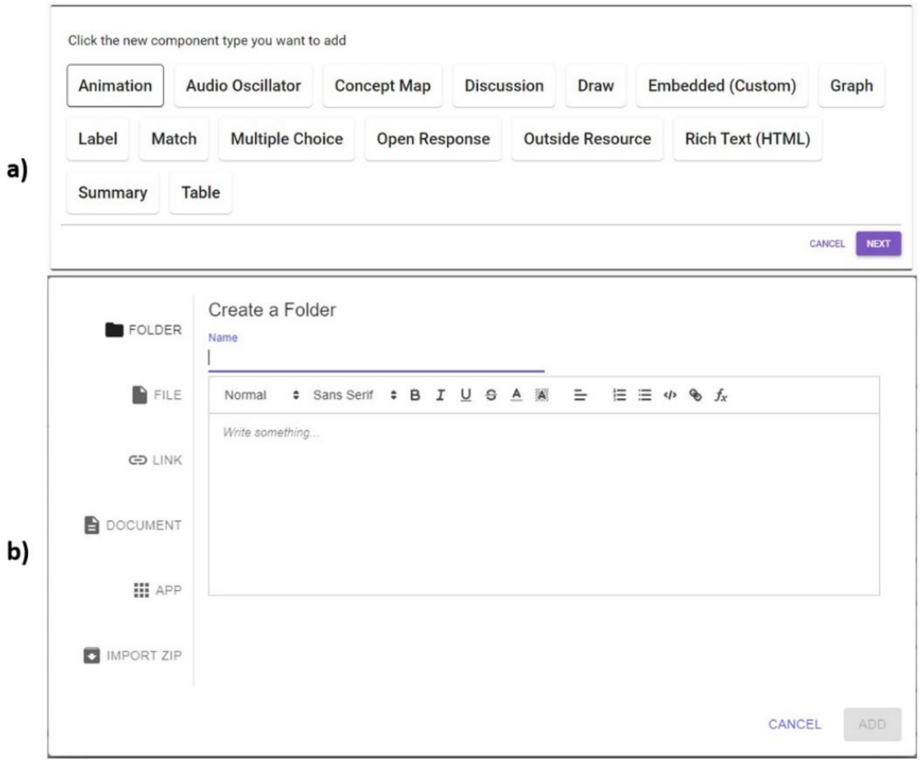


Fig. 6.12: Items that can be added in an IBL space utilizing a) the WISE platform and b) the Graasp platform

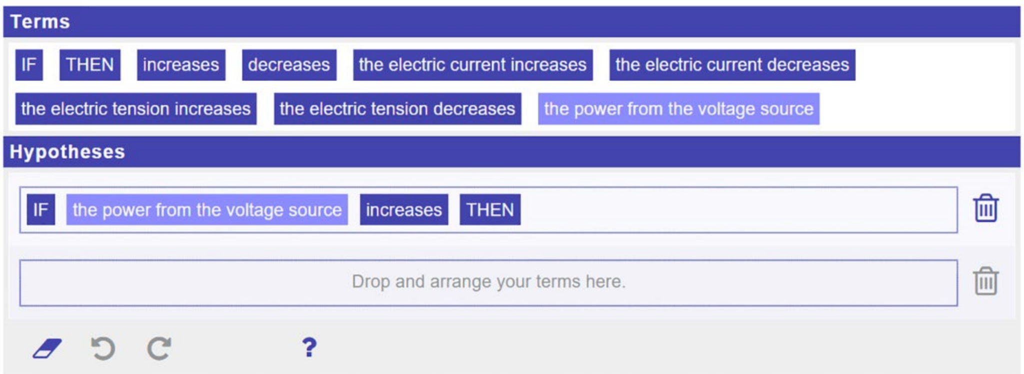


Fig. 6.13: An example of a configuration of the Hypothesis Scratchpad tool in the Graasp platform

Another example of an interesting scaffolding tool offered by Graasp is the Experiment Design tool (Figure 6.14). The tool structures the process of experimental design, which is often considered a complex and challenging task for learners, as a three-step, serial process. Learners first identify the independent, controlled, and dependent variables, then they assign values to their variables and, finally, they set up experimental trials. The teacher modifies the properties and measurements that appear on the left side of the tool and, similarly to the Hypothesis Scratchpad, they can complete one or all of the three steps in the tool to adjust the level of scaffolding provided to learners according to their needs. If a teacher chooses to give learners a given experimental design, then the only action that learners must take is to record the measurements of the dependent variable(s). In other words, this constitutes a *closed* form of the inquiry sub-step *Planning and Conducting Investigation*, while if learners have to complete the three steps in the tool, then we move from the *closed* form to the *moderately opened*.

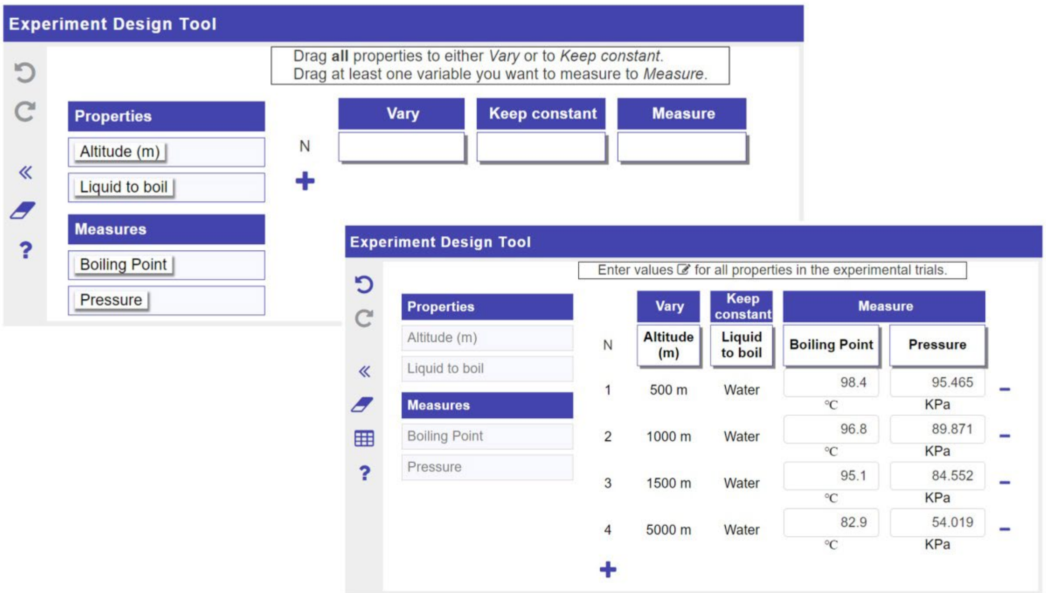


Fig. 6.14: An example of a configuration of the Experiment Design tool on the Graasp platform

As mentioned above, we believe that it is beneficial to use various sources of scaffolding and combine several methods that may help learners to move from a lower degree of openness to the next. Moreover, the use of technology-based scaffolding is recommended, especially when teaching and learning are challenged, such as during the COVID-19 pandemic. Among the most important consequences of the COVID-19 pandemic on education were the transition to distance learning and the preparation of teachers and educational systems within a very short time (Chiemeke & Imafidor, 2020). In addition, learner support during distance learning was questioned (Huber & Helm, 2020). So, the scaffolding methods we chose to present in this chapter can be used in many ways and by means of technology to support teachers when differentiating an IBL lesson.

6.4 Assessment for planning and implementing differentiation

When a teacher starts to plan the differentiation for a lesson (or a longer teaching sequence), they need to define the expected learning goals and the learner prerequisites to achieve these goals. In other words, the teacher needs to differentiate according to the *readiness*[3] of an individual learner,

[3] Differentiation can be implemented according to the learners' readiness, interests, or learning profile (Tomilson & Moon, 2013, Boyle & Charles, 2014). This chapter focuses only on readiness.

which refers to the learner's proximity to the specified learning goals (Tomlinson & Moon, 2013). The readiness must be pre-assessed by formative assessment methods, which are referred to here in short as *pre-assessment*. Later, when the teacher implements the planned lesson, they need to formatively assess learners' progress; this is referred to as *ongoing assessment*. These two phases of formative assessment are crucial for successful differentiation, since the planning must be based on learners' existing knowledge and skills; meanwhile, the need for and suitability of the scaffolding during the teaching must be justified by ongoing formative assessment.

(A) Pre-assessment for the differentiation decisions 1-4

Usually, teachers have a long-term understanding of their learners' knowledge and skills which is based on previous discussions, observations, tests, and exams. Naturally, teachers utilize this data when considering individual needs in the planning of differentiation. The actual pre-assessment can take many different forms and the time that pre-assessment takes can vary widely. For example, before a lesson, a teacher may informally discuss with learners their ideas concerning the target phenomenon. A widely used method is to present a conceptual multiple-choice question or a concept cartoon (see Table 6.2), give a short time for thinking individually or in pairs/groups, before collecting learners' answers using response cards (e.g., A-D) or use a classroom response system (CRS) which collects the answers and presents them on a screen – for example, as a bar chart. In this way, the teacher quickly gets data about learners' conceptual understanding and they can use this information to plan the next teaching steps. CRSs have many benefits, such as fast access to learners' answers and anonymity of answers (which is useful if learners feel uncomfortable expressing their thoughts). CRSs can be implemented using clickers, which means each learner has their own input device for answering. However, there are many free mobile applications, such as Socrative, Kahoot and Mentimeter which can be used as a CRS on smartphones, tablets, or laptops. More structured forms of pre-assessment are, for example, conceptual tests or interest surveys. Such questionnaires take more time but can be very useful when planning a longer teaching sequence.

The first differentiation decision (see Figure 6.15 or Figure 6.1) is *grouping*, which also includes the option of individual work. Flexible grouping is an essential part of effective differentiation (Boyle & Charles, 2014; Tomlinson & Moon, 2013), meaning the grouping is varied often, giving learners the opportunity to work with many peers whose ability level may be similar to or different than their own. The most suitable grouping decision depends on the task and other circumstances, such as individual abilities, but it should be based on pre-assessment. Let's imagine that a teacher gets information from a conceptual question that some learners hold a misconception, for example "the electric current is consumed when it flows through a closed circuit". The teacher forms a homogenous group of these learners and gives them the task to measure the current in different points of a closed circuit comprised of a battery and light bulbs. The teacher may give a different task to another group depending on their preconceptions on direct current circuits. In a different lesson, a teacher may form a heterogenous group, since they know how to leverage learners themselves as instructional resources in peer learning. Sometimes, individual work is the proper choice, for example if a learner has a temporary difficulty with working with others, if the work requires using equipment such as a microscope that allows only one learner to use it at a time, or if individual work may then lead to peer learning, such as in the jigsaw approach, where learners gain expertise in one aspect and then teach their peers what they have learned.

In the second differentiation decision, the teacher needs to decide on the openness of the sub-phases for each group or individuals. This decision cannot be disconnected from the first decision, because the teacher may group learners based on their current abilities in relation to the sub-phases. For individual learners and homogenous groups, the teacher can use their knowledge to assess the suitable level of openness. For heterogeneous groups, the second and third differentiation decisions should be used to design a task that is both feasible for the less advanced members of the group while remaining challenging for the more advanced members. The more advanced peers can then support the rest of the group in their work.

Similarly, the third decision is connected to the first and the second decisions. The teacher should use the information available to them to choose the proper sub-phase of inquiry to extend in the lesson or teaching sequence.

In the fourth differentiation decision (scaffolding decision), the pre-planned hard scaffolds (see Chapter 2, *Differentiation and scaffolding*) should be designed based on the pre-assessment. Different learners or groups might benefit from different modes of hard scaffold. For example, the teacher may preparate various prompts or step-by-step help cards (see Table 6.2) for different difficulty levels.

All in all, although the differentiation process is divided into four decisions, this is done mainly to conceptualize the planning process. When planning lessons, teachers need to consider all of the decisions together and use the same pre-assessment data as the basis for those decisions.

(B) Ongoing assessment for differentiation decision 4

Scaffolding can also be implemented through soft scaffolds (see Chapter 2, *Differentiation and scaffolding*) which refers to scaffolding provided during the learning process, often “on-the-fly”. As the teacher is observing the learners or groups working on their inquiry task, they might observe that the hard scaffolds planned do not provide enough support for the learners. Or they might hear one group having a discussion that reveals a misconception that cannot be corrected through the inquiry activity itself. These events should prompt the teacher to provide additional soft scaffolding through various means, such as whole-group discussions or targeted support.

Peer learning can also be used as a soft scaffold by having the other learners or groups assess and observe the work that a learner or group is doing.
Also, self-assessment can be used to provide information for the teacher to possibly provide soft scaffolds, for example by having the learners assess their work during the lesson by using an evaluation rubric with predefined criteria.

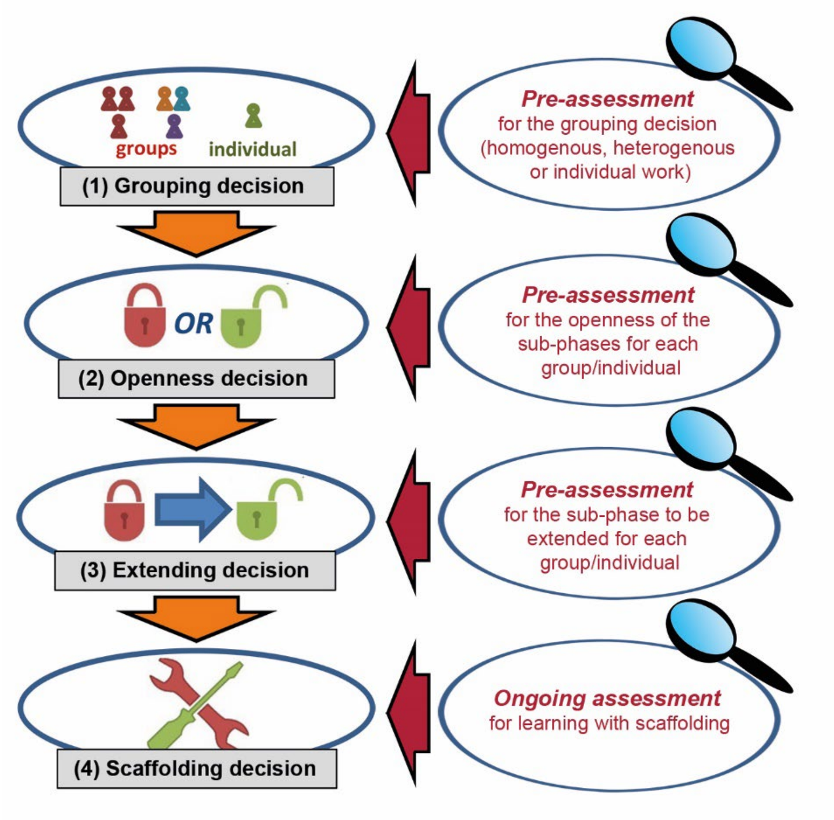


Fig. 6.15: Schematic diagram summarizing the four decisions of the Differentiation Tool

Summary

To plan differentiated IBL lessons, various decisions and assessments are required.

After choosing the domain to which the lesson is oriented, four differentiation decisions must be made:

(1) Grouping decision: the setting of the lesson must be selected. Should the lesson be conducted in homogeneous or heterogeneous groups, or in individual work?
(2) Openness decision: the relative openness of the sub-phases for each group of learners or for each individual working learner must be determined.
(3) Extending decision: the sub-phase(s) in which openness shall be extended must be selected.

(4) Scaffolding decision: a suitable method for scaffolding to extend the selected sub-phase(s) must be selected.

The four differentiation decisions and possible methods (see Table 6.1 and 6.2 for examples) are referred to as the Differentiation Tool, because they build up a tool for lesson planning.

At different stages of planning and conducting a lesson, pre-assessment or ongoing assessment is necessary (see Figure 6.15).

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7 Teaching examples: application of the Differentiation Tool

Disclaimer:
The described experiments were tested and carefully described in advance. Nevertheless, users are obliged to check for any errors or inaccuracies before carrying out the examples described. The authors assume that performers have the necessary knowledge and skills to carry out the described experiments.
Attention: general safety instructions must always be observed! The use of these lesson descriptions is at your own risk. Liability for damage or loss arising from handling the substances, materials or equipment described herein is excluded; as well as claims for damages or warranty claims due to incorrect or missing information. The authors thus expressly exclude any direct or indirect liability for damages in connection with the implementation of the described teaching examples.

7.1 Swelling and shrinking of wood (Biology, suitable for grades 6–7)

Factual information

In the Stone Age, people observed stones being processed by nature: water would get into cracks and crevices, then sometimes freeze and expand. This expansion could cause parts of a stone to blow off (this is called "frost shattering"). Stone Age people also learned that when dry wood is moistened with water, it expands. They combined both findings and used them to process stones similarly to nature. The processing of the stones – the dimensionally accurate forming – was carried out with wooden wedges. The wooden wedges were driven into crevices in stones and then watered. Later, iron chisels and wedges were also used. With the use of a chisel, people became independent of natural stone crevices. Small holes were prepared, and iron wedges were driven into these to split the stone (see Fig. 7.1.1).

Source: Translated from German; *Arbeitsgemeinschaft Praktische Archäologie* (https://blog.amh.de/merkwuer-dige-loecher; retrieved on 11 October 2021)

Fig. 7.1.1: Ancient stone with holes for stone splitting: photo by Christa Sallam, 2018

The lesson described below concerns the processing of stones using the swelling of wood. Wood swells and shrinks according of the dampness of its surroundings. When the wood is drier than the environment, it absorbs dampness and swells. When swelling, the length of the wood changes moderately in the radial direction (see Fig. 7.1.2) and very strongly in the direction of the annual rings (tangentially). In the longitudinal direction, wood size changes are minor. The enlargement depends on the type of wood: beech wood swells more than pine wood, for example. Conversely, wood shrinks when dry, which means that the wood's dimensions are reduced.

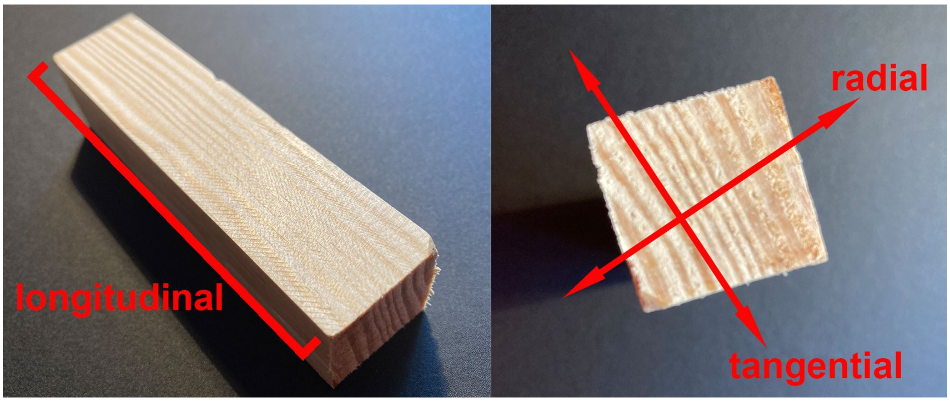


Fig. 7.1.2: Anatomic of wood

Determination of the objective (domain of the lesson):

The lesson targets the procedural domain. The core of the teaching is to foster (train) competencies of the inquiry sub-phases.

The four decision stages of the Differentiation Tool:

1. Selection of setting

In this example, the learners are divided into homogenous groups by the teacher so that all group members are given tasks of appropriate complexity . The learning objectives are the same for all learners in the groups; however, the level of support is different.

2. Selection of the relative openness of the sub-phases

Figure 7.1.3 shows the degrees of openness in inquiry-based learning that are chosen for the groups (two fictitious groups are shown as examples). The different colors – orange and yellow – represent the different groups. As can be seen in Figure 7.1.3, all groups are given a problem (sub-phase *closed*). Both groups are different in their abilities. For group 1 in sub-phase *Questioning,* a moderate openness (*moderately opened*) is selected. The group is offered various research questions to choose from. For group 2 the sub-phase *Questioning* is *opened*. Group 2 formulates a question with assistance in the form of on-the-fly feedback from the teacher. In the sub-phase *Hypothesis Generation*, both groups can formulate hypotheses with the help of a checklist (see Appendix 7.1.IV) according to their abilities. The sub-phase is *opened*. The sub-phases *Planning and Conducting Investigation* and *Conclusion* are *moderately opened* for group 1 and *opened* for group 2. In sub-phase *Planning and Conducting Investigation,* group 1 is supported with a

list of materials and group 2 selects, if necessary, materials with little support from the teacher. For *Data Interpretation,* group 1 is offered the choice of displaying the results in a table or in a bar chart. Group 2 receives on-the-fly-feedback. In the sub-phase *Conclusion,* the *opened* form is selected for both groups. For help in this sub-phase, verbal prompts are given in a class discussion (possible prompts: “Is the hypothesis proven/refuted? How can this be recognized? Has the research question been answered? Were there any measurement deviations? How were they handled? What ambiguities/problems have occurred?”).

		0 closed	*1 moderately opened*	*2 opened*	*3 open*
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
Conceptualization	**Hypothesis Generation**	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a hypothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
Investigation	**Data Interpretation**	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	Learners develop their own conclusion

group 1
group 2

Teacher-directedness → **Student-directedness**

Fig. 7.1.3: Degrees of openness

3. Selection of sub-phases to be scaffolded to the next level

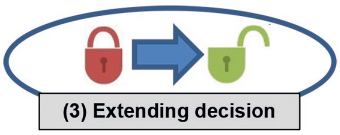


Figure 7.1.4 shows the sub-phases that are extended to a higher level of openness.

Learners in the *moderately opened* level of *Questioning* (group 1) are supported to reach the *opened* level. The learners of group 2 in the *opened* level are supported to arrive at the level *open*. This is done analogously in the sub-phase *Planning and Conducting Investigation.*

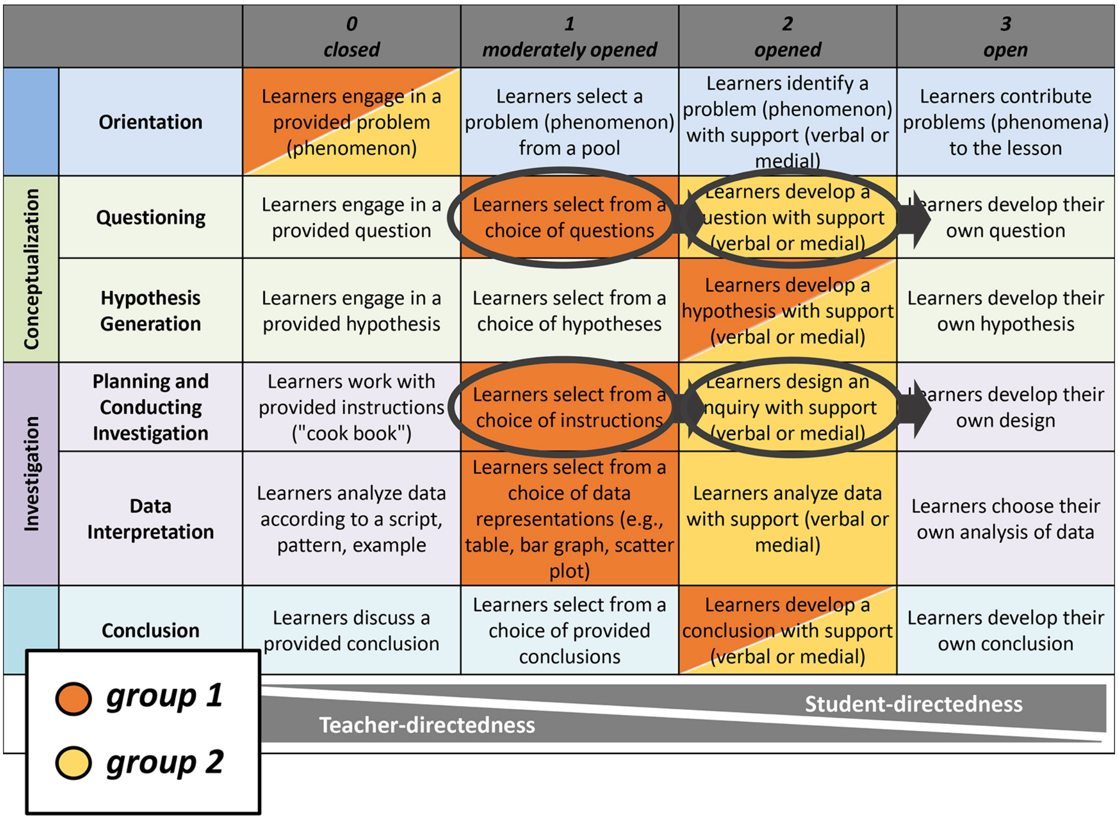


Fig. 7.1.4: Extensions for the two example groups

4. Selection of methods for scaffolding

In the sub-phase *Questioning,* a checklist is chosen as a scaffolding method for both groups (see Appendix 7.1.III). A checklist is suitable for both degrees of openness. In addition, the teacher offers help if necessary.

In the sub-phase *Planning and Conducting Investigation,* step-by-step help cards are chosen as a scaffolding method for both groups to lead them to the next level of openness (see Appendix 7.1.VI). For each degree of openness, a different set of help cards is used. The scaffolding methods should lead to the next degree of openness. The method of scaffolding and the method that builds the level of openness are combined. An example of such a combination: in the sub-phase *Planning and Conducting Investigation*, group 1 receives a list of materials that contains not only necessary equipment and material, but also redundant items. The help cards reduce the material list step by step until only the necessary materials are available.

Lesson plan

<table>
<tr><td>Grade: 6–7</td><td>Subject domain: Biology (Engineering/technical instruction is also possible)</td><td colspan="2">Topic: Swelling and shrinking of wood</td><td>Duration: 60 min</td></tr>
<tr><td colspan="5">Prior knowledge:
Before the lesson, learners:
know that there are different types of wood (beech wood, spruce wood, etc.), which differ in their properties;
can measure lengths with a sliding caliper;
know that an experiment needs test and control trials;
know that an experimental report and an experiment consists of different sections (question, hypothesis...) and know what is expected in each.</td></tr>
<tr><td colspan="5">Driving question: Learners are encouraged to think about how moisture affects wood.</td></tr>
<tr><td>Learning objectives: must be feasible to put into operation and measurable against the learning products</td><td>Teaching/learning material: reference material, physical or virtual materials and resources</td><td>Learning activity: a description of what learners do, including the instructional support they receive</td><td>Learning product: needs to reflect knowledge or skills included in the learning objectives and allow a flow of learning activities</td><td>Assessment (formative, peer, or summative): focused on learning products</td></tr>
<tr><td rowspan="2">Learners plan and conduct an inquiry activity (an experiment).</td><td>Pictures (Appendix 7.1.I)</td><td>The teacher shows the learners pictures. The learners explain what they can see in the pictures. The teacher tells the learners that the stone seen in the pictures is very old and was processed by people who lived a long time ago.</td><td></td><td></td></tr>
<tr><td>Text (Appendix 7.1.II)
Checklist (Appendix 7.1.III)</td><td>The learners first read the text individually, then state a research question. In the next step, they discuss the stated research questions in their groups and select one question per group (cooperative learning).
Transition from moderately opened to opened: the learners select a suitable research question from a pool of given questions. For this work they use the checklist. Possible</td><td>Research question</td><td>Observation in class; if necessary, verbal aids are given in the form of prompts.</td></tr>
</table>

		questions (can be made available to learners on a worksheet): "How did people work on stones in the Stone Age? How has the approach to processing stone with iron tools changed? What effect does moisture have on wood? What effect does moisture have on the length and width of a wooden block? What happens when damp wood dries?" Transition from *opened* to *open*: Learners formulate research questions using fewer given words available on help cards (Help 1: Effect; Help 2: Water; Help 3: Wood width). As a scaffold, they also use the checklist (Appendix 7.1.III).		
	Checklist (Appendix 7.1.IV)	The learners generate hypotheses individually, discuss them in the next step in their groups, and select one hypothesis per group. For help, they use a checklist.	Hypothesis	Observation in class; if necessary, prompts are given.
	Figure: Material selection (Appendix 7.1.V) Help cards (Appendix 7.1.VI)	The learners plan an experiment in their groups according to their hypotheses. Everyone receives the hint that time must be taken into account until something can be seen/measured (the observation is the next day). All plans must be briefly presented to the teacher before they are carried out (it is suitable for the learners to make a sketch that illustrates the implementation or to describe the implementation in writing). Transition from *moderately opened* to *opened*: learners select the material for their experiments from a pool of materials. Help	Planned experiment	Observation in class; if necessary, prompts are given. Planning sketches could be used for assessment.

		cards offer hints as to which materials are not necessary. Transition from *opened* to *open*: learners think about suitable materials and plan an experiment. Help cards provide hints.		
		Learners write down their measurements in a table or record them in a diagram. The group working in the *moderately opened* level chooses one of the two ways of representing their data (table or diagram). The other group decides for themselves what a suitable data representation is. The teacher gives support if necessary.	Data presentation	Observation in class; if necessary, prompts are given.
		In a class discussion, conclusions are drawn and the process is reflected upon.	Conclusion	

Appendix 7.1.I – Pictures for the introduction phase

Source: Pictures by Christa Sallam, 2018

Appendix 7.1.II – Text for problematizing

The people of the Stone Age learned how to cut stones by watching natural processes. In natural processes, water gets into cracks and crevices of stones. If the temperature drops below 0° Celsius, water becomes ice. When water freezes, it expands. Due to the expansion, parts of the stone can be blown off. This process is called “frost shattering”.

The people of the Stone Age also learned that dry wood is suitable for “blasting off”. This wood-blasting technique was used in the Stone Age to cut stones. For the processing of stones, wooden wedges were hammered into existing stone cracks and the wooden wedges were doused with water.

Later, the people also used chisels and wedges made of iron. As a result, they were no longer dependent on natural cracks.

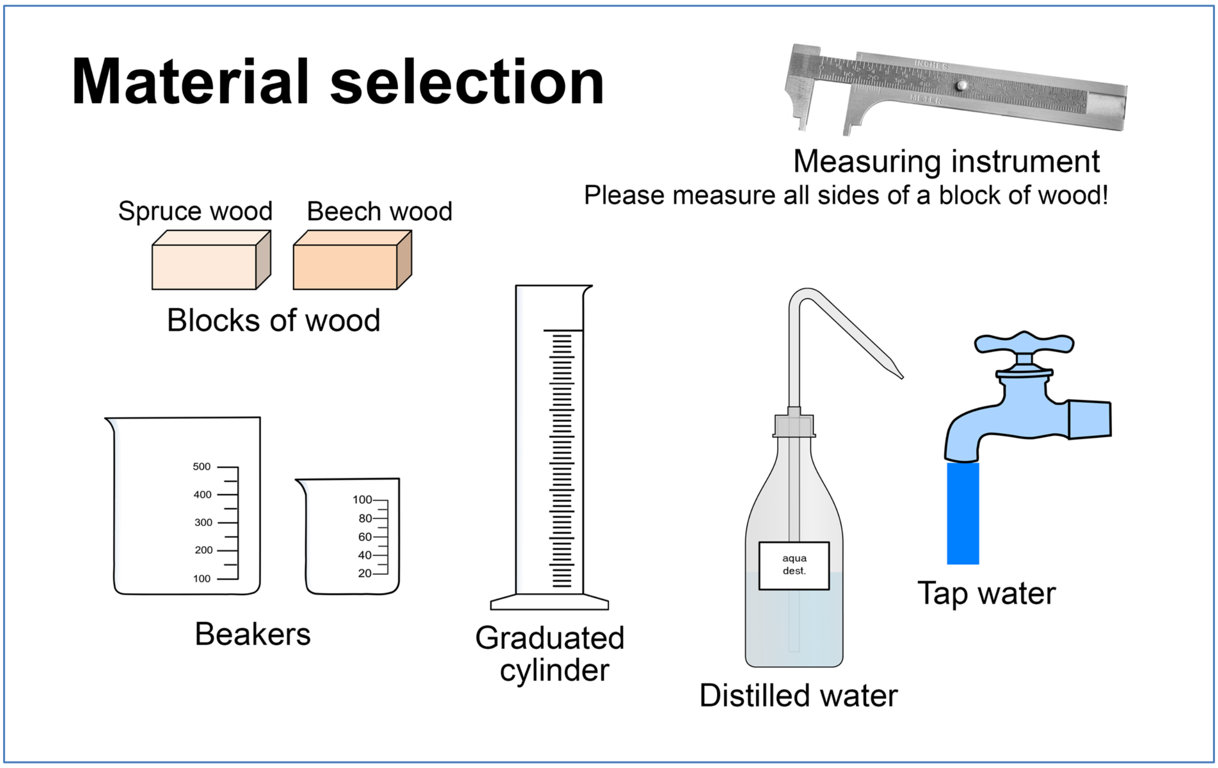
Appendix 7.1.III – Checklist for *Questioning*

Checklist for auditing a question			
1	Does the question match the problem (the content from the text)?	Yes [ ]	No [ ]
2	Is the question related to a natural phenomenon? (A “natural phenomenon” is a process of nature.)	Yes [ ]	No [ ]
3	Can the question be answered with the use of an experiment?	Yes [ ]	No [ ]
4	If there is a cross in a “no” box, then a new research question must be formulated!		

Appendix 7.1.IV – Checklist for *Hypothesis Generation*

Checklist for auditing a hypothesis (assumption)			
1	Is the formulated hypothesis (assumption) a possible answer to the research question?	Yes [ ]	No [ ]
2	Is the hypothesis (assumption) formulated as an “If…, then…” sentence?	Yes [ ]	No [ ]
3	Is the supposed variable written after the word “if”?	Yes [ ]	No [ ]
4	Is that which is to be measured/observed written after the word “then”?	Yes [ ]	No [ ]
5	If there is a cross in a “no” box, then the hypothesis (assumption) must be reformulated!		

Appendix 7.1.V – Material pool



Work tasks:

(1) Please work with pencil!

(2) All materials are available in any number or amount.

(3) Delete any materials you don't need for your experiment.

(4) Plan an experiment with the material to test your hypothesis (assumption).

(5) You can use the green cards if you need help.

Appendix 7.1.VI – Step-by-step help cards (Green: transition from *moderately opened* to *opened*; Orange: transition from *opened* to *open)*

Help 1: The different types of wood (beech, spruce...) could react differently. Limit yourself to one type of wood.

Help 2: All trials must be carried out in the same vessels. Choose one type of vessel and cross out all other vessel varieties on the list.

Help 3: The water must be the same in its composition in all trials. Selects either distilled water or tap water.

Help 4: It is possible to submerge the wooden block or make it wet again and again. For submersion, an additional weight is required.

Hint: The wood must be measured on all sides.

Help 1: The different wood species (beech, spruce ...) could react differently. It is harder to plan an experiment that studies different types of wood.

Help 2: You must use wooden blocks of the same sizes.

Help 3: Have you planned a test and a control trial?

7.2 Neutralization of stomach acid (Chemistry, suitable for grades 9–10)

Factual information

Stomach acid is hydrochloric acid, a strongly acidic solution. Stomach acid rising from the stomach into the esophagus is called “heartburn”. Taking a remedy for heartburn, such as example Rennie®, Bullrich Salz® or Trigastril®, neutralizes the stomach acid. Neutralization is detectable with, among other things, a universal indicator, which turns red in hydrochloric acid, blue in the remedy and green in the combination of stomach acid and remedy.

The specific active ingredient varies from remedy to remedy. For example, Rennie® contains calcium carbonate and magnesium carbonate, Bullrich Salz® sodium bicarbonate (baking soda) and Trigastril® aluminium oxide and magnesium hydroxide. However, these differences do not play a role in the phenomenon of “neutralization” to be discussed in this lesson.

Hydrochloric acid	+	Magnesium carbonate	→	Water	+	Carbon dioxide	+	Magnesium chloride
2 HCl	+	$MgCO_3$	→	H_2O	+	CO_2	+	$MgCl_2$

Hydrochloric acid	+	Sodium bicarbonate	→	Water	+	Carbon dioxide	+	Sodium chloride
HCl	+	$NaHCO_3$	→	H_2O	+	CO_2	+	NaCl

Hydrochloric acid	+	Magnesium hydroxide	→	Water	+	Magnesium chloride
2 HCl	+	$Mg(OH)_2$	→	2 H_2O	+	$MgCl_2$

If a remedy is used that produces carbon dioxide, gas development can be observed. The gas can be introduced into lime water and causes turbidity there (the so-called “lime water test”).

Calcium hydroxide solution	+	Carbon dioxide	→	Calcium carbonate	+	Water
$Ca(OH)_2$	+	CO_2	→	$CaCO_3$	+	H_2O

The experiment is very well-suited for a practical task in the context of a performance test (summative assessment), since existing knowledge is applied to an everyday phenomenon and the experiment is only slightly complex.

Determination of the objective (domain of the lesson):

The focus of this lesson is on the procedural domain. The learners apply existing knowledge and practice independently planning, executing, and drawing conclusions from experiments. Space is given to the reflection of the experimentation process at the end of the lesson.

The four decision stages of the Differentiation Tool:

1. Selection of setting

Learners can carry out the experiment individually or in partner work. The former is useful if the experiment is to be carried out in the form of a performance test. If the experiment is not carried out as part of a performance test, partner work has the advantage over using larger groups in that everyone can participate in practical work. Compared to individual work, there is also the advantage that the individual steps can be communicated directly. For targeted support, it makes sense to assign the learners to the pattern groups 1 and 2 (see below and Figure 7.2.1). The partner pairs are allowed to form themselves independently.

2. Selection of the relative openness of the sub-phases

Figure 7.2.2 shows which degrees of IBL openness have been selected for the partner groups as examples. In our example, we have partner groups that work in the group 1 pattern and partner groups that work in the group 2 pattern. As Figure 7.2.2 shows, the *Orientation* phase is *opened* for everyone. The learners deal with the phenomenon in a classroom discussion with the help of an advertising film (examples can be found on YouTube). Afterwards, each partner group develops a resulting question. The sub-phase *Questioning* is *opened*, as the teacher can help at any time. Subsequently, the learners can check their question with the help of the checklist for reviewing a question (see Appendix 7.2.II).
If the experiment is part of a performance test, a short information text on heartburn can be used for orientation (see Appendix 7.2.I). For this purpose, however, the question should be *closed*. All other phases would be *open* for a performance test.
The phase of *Hypothesis Generation* is *moderately opened* in the learning process for the learners in the group 1 pattern with a competency extension (see below). For the learners in the group 2 pattern, this phase is *opened.* They use the checklist for testing a hypothesis as a support (see Appendix 7.2.III).

Furthermore, the teacher is available to everyone for on-the-fly assistance. The *Planning and Conducting Investigation* sub-phase is again *opened* to learners in the group 1 pattern. Learners are only provided with a list/box of materials from which they can choose (see Appendix 7.2.V). The learners in the group 2 pattern plan the experiment: this sub-phase is *open.* Learners in the group 2 pattern should be able to cope with this sub-phase without assistance. The exception to this is the safety check of learners' planned experiments by the teacher before execution. While the experiment is being conducted, the teacher naturally intervenes in safety-related issues. *Data Interpretation* is *opened* for all. In this experiment, no special data presentation is necessary, and the teacher can provide support on-the-fly. The *Conclusion* is *opened* for all and can be done in a whole-class discussion. The teacher supports this with targeted questions.

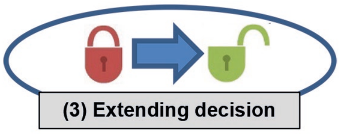
		0 closed	*1 moderately opened*	*2 opened*	*3 open*
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
Conceptualization	**Hypothesis Generation**	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a hypothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
Investigation	**Data Interpretation**	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	Learners develop their own conclusion

group 1
group 2

Teacher-directedness — Student-directedness

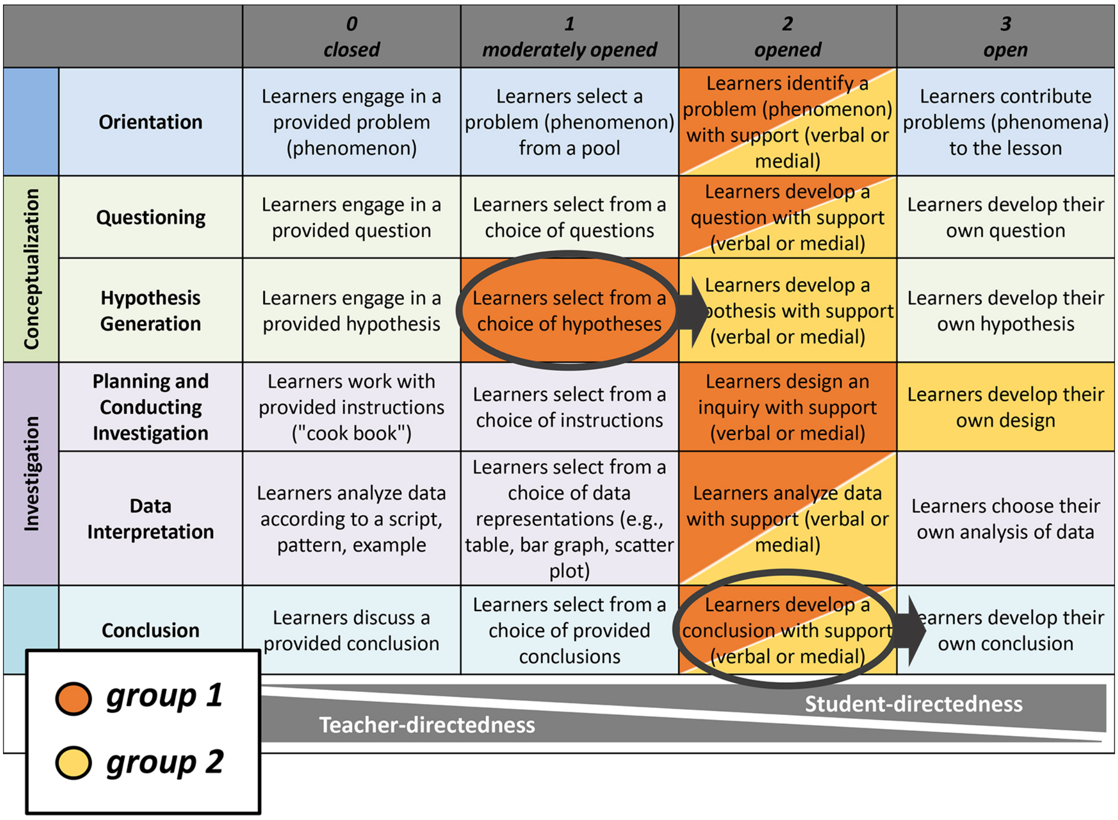
Fig. 7.2.1: Degrees of openness

3. Selection of sub-phases to be scaffolded to the next level



Since many sub-phases already take place at the *opened* or even *open* level in this lesson, only in a few cases does an expansion of competencies make sense at all. Figure 7.2.2 shows which sub-phases are to be extended in their degree of openness in this lesson.

For the learners in the group 1 pattern, an expansion of competence in the sub-phase *Hypothesis Generation* to the *opened* form is sought. All learners (in the group 1 and group 2 patterns) should be supported in the sub-phase *Conclusion* towards the degree *open*.



		0 *closed*	*1* *moderately opened*	*2* *opened*	*3* *open*
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
	Hypothesis Generation	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a pothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
	Data Interpretation	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	earners develop their own conclusion

Fig. 7.2.2: Extensions for the two example group patterns

4. Selection of methods for scaffolding

For the learners in the group 1 pattern, an expansion of competencies in the phase *Hypothesis Generation* is sought. This is to be achieved by means of step-by-step help cards (see Appendix 7.2.IV) and on-the-fly feedback from the teacher. All learners will be scaffolded in the sub-phase of *Conclusion* in the direction of the degree *open*. Help cards (see Appendix 7.2.VI) are used for this purpose, which can be used sparingly and in a targeted manner. The teacher can also provide support.

Lesson plan

Grade: 9–10	**Subject domain:** Chemistry	**Topic:** Neutralization of stomach acid		**Duration:** 90 min
Prior knowledge: Learners already know that: ▪ acidic solutions turn a universal indicator red, alkaline solutions blue and neutral solutions green; ▪ acidic solutions can neutralize alkaline solutions and vice-versa; ▪ stomach acid is hydrochloric acid. Learners already be able to: ▪ formulate hypotheses in relation to questions; ▪ plan simple experiments to test their hypotheses; ▪ draw conclusions from observations.				
Driving question: The learners investigate how remedies for heartburn work.				
Learning objectives: must be feasible to put into operation and measurable against the learning products	**Teaching/learning material:** reference material, physical or virtual materials and resources	**Learning activity:** a description of what learners do, including the instructional support they receive	**Learning product:** needs to reflect knowledge or skills included in the learning objectives and allow a flow of learning activities	**Assessment (formative, peer, or summative):** focused on learning products
	Advertising film (examples on YouTube) or info text (see Appendix 7.2.I)	The learners watch a short advertising film about a remedy for heartburn. Alternatively, heartburn can also be presented via the info text. In the classroom discussion, learners find out that heartburn is caused by rising stomach acid (hydrochloric acid) that can be treated by the remedy.		
The learners plan an investigation and experimentally determine the effect of gastric	Checklist for reviewing a question (see Appendix 7.2.II)	Based on the problem, the research question is formulated. The learners first formulate the question individually and then compare it with their partner. Agreement must be	Research question	Observation in the classroom by the teacher; if necessary, they offer support.

medicine on stomach acid (hydrochloric acid).		reached. The question must be checked using the checklist. Suitable questions are: "What effect does the remedy have on stomach acid? Does the remedy neutralize stomach acid? How can the remedy fight stomach acid? etc."		
	Checklist for reviewing a hypothesis (see Appendix 7.2.III) Step-by-step help cards for formulating a hypothesis (see Appendix 7.2.IV)	The learners formulate a hypothesis in the form of an "If…, then…" sentence. Again, this happens first as individual work and then in coordination with the partner. Learners in the group 2 pattern are supported by the teacher on-the-fly and receive the checklist. Transition from *moderately opened* to *opened*: Learners in the group 1 pattern can use the help cards – card 1 must be used – and need to use the checklist. Each pair uses only as many help cards as necessary. The teacher provides support if necessary.	Hypothesis	Observations in the classroom by the teacher; support if necessary with the help of prompts.
	List (see Appendix 7.2.V) or box of materials with: test tube stand, 3 test tubes (alternatively, Petri dishes), water, stomach acid (hydrochloric acid), remedy, universal indicator, stopper, and other materials to choose from that are not (necessarily) needed	The learners first plan the experiment individually, then carefully formulate the individual implementation steps with their partner. Learners in the group 1 pattern receive a list or box of materials as a support. Learners in the group 2 pattern are allowed to choose from all the materials available in the room. After the safety check by the teacher, the learners perform the experiment in pairs. The teacher makes sure the learners wear safety glasses. The following approaches are necessary: - Stomach acid (hydrochloric acid) with universal indicator	Planned experiment	Observations in the classroom by the teacher; if necessary, they offer support.

		- Remedy dissolved in water (possibly with universal indicator) - The two solutions are gradually combined until the universal indicator turns green.		
		Learners record their observations and interpret the changing indicator color. Depending on the remedy, a gas is still produced. Particularly fast or high-performing groups receive the additional instruction to develop proof of the gas.	Data notation	Observations in the classroom by the teacher; support if necessary with the help of prompts.
Learners can explain the effect of gastric medication on stomach acid (hydrochloric acid).	Help cards (see Appendix 7.2.VI) Blackboard text for conclusion (see Appendix 7.2.VII)	The observations and conclusions will be discussed in a whole-class session. Transition from *opened* to *open*: the learners should create the blackboard text in partner work. The teacher provides economical, targeted and individual support with the help of help cards and other assistance. The reaction equations pose a particular challenge and can only be expected at the higher school level (extended level).	Conclusion	
Closing: The lesson ends with a reflection on the IBL process and personal learning progress. If one or more groups work particularly fast, the follow-up question “Which gas is produced?” can be pursued. Alternatively, this question can be discussed in plenary or in the following lesson after the conclusions.				

Appendix 7.2.I – Info text

When stomach acid rises from the stomach, you can feel so-called “heartburn” behind the sternum. Under certain circumstances, this painful sensation can rise to the neck and throat. Often, heartburn is accompanied by acid eructation (burping). Heartburn can be treated with various medications such as Rennie®, Bullrich Salz®, or Trigastril®.

Appendix 7.2.II – Checklist for reviewing a question

Checklist for reviewing a question:

- ☐ Does the question have anything to do with the main topic of the current chemistry lessons?
- ☐ Does the question fit our problem?
- ☐ Is the question experimentally verifiable so that a rule can be derived afterwards?

If you can't answer “yes” to all of these questions, you’ll need to either modify your question or formulate a new question.

Appendix 7.2.III – Checklist for reviewing a hypothesis

Checklist for reviewing a hypothesis:

- ☐ Is the hypothesis a possible answer to the question?
- ☐ Can you justify your hypothesis with your previous knowledge?
- ☐ Does the hypothesis indicate the expected result?
- ☐ Is the hypothesis formulated as an “If…, then…” sentence?

If you can’t answer “yes” to all of these questions, then you'll need to change or reformulate your hypothesis accordingly.

Appendix 7.2.IV – Step-by-step help cards for formulating a hypothesis

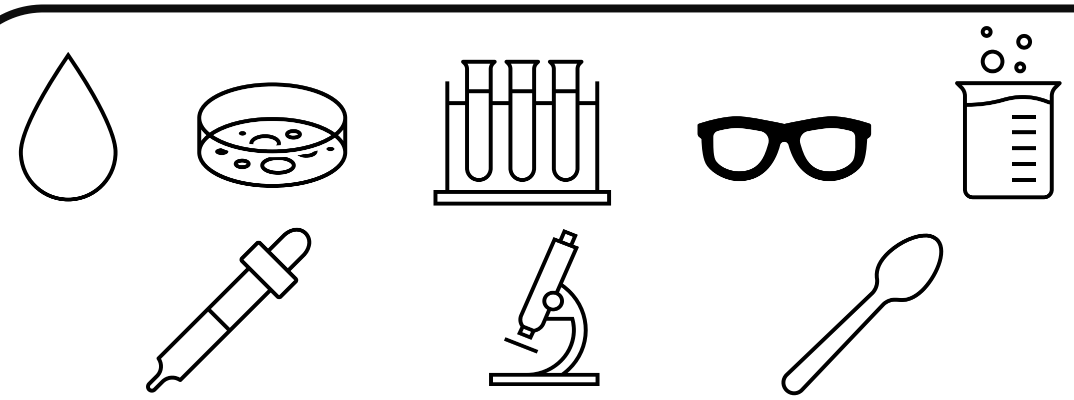
Help 1: Write down three possible answers to your question.

Help 2: Which of the answers can be answered with an experiment? Delete all the others. If several questions are possible, choose one of them.

Help 3: Does the answer mention what you think will change/happen?

Help 4: Does the answer mention what you think is the trigger for what is happening?

Appendix 7.2.V – List of materials (can be handed out to learners as a copy or as a box)



Appendix 7.2.VI – Help cards for the conclusion

What do the colors of the universal indicator mean?	What reactants do I have?	What products have been created?
What is the formula of hydrochloric acid?	What substance is produced during each neutralization?	The resulting gas clouds lime water.
What active ingredi-ent is in the remedy?	What is the formula of the active ingredi-ent?	Among the products is a salt.

Appendix 7.2.VII – Blackboard text

Stomach acid is an acidic solution (hydrochloric acid). This is proven by the red indicator color.

The remedy is an alkaline compound, which is shown by the blue indicator color.

If the acidic and alkaline solutions are added together, the substances neutralize each other. This is made clear by the green color of the indicator.

Reaction scheme (select depending on the active substance):

Hydrochloric acid	+	Magnesium carbonate	→	Water	+	Carbon dioxide	+	Magnesium chloride
Hydrochloric acid	+	Sodium bicarbonate	→	Water	+	Carbon dioxide	+	Sodium chloride
Hydrochloric acid	+	Magnesium hydroxide	→	Water	+	Magnesium chloride		

Reaction equation (select depending on active substance):

2 HCl	+	$MgCO_3$	→	H_2O	+	CO_2	+	$MgCl_2$
HCl	+	$NaHCO_3$	→	H_2O	+	CO_2	+	NaCl
2 HCl	+	$Mg(OH)_2$	→	2 H_2O	+	$MgCl_2$		

7.3 Metals react with acid (Chemistry, suitable for grades 9–10)

Factual information

Acidic solutions can etch metals. This produces a salt that can be obtained by evaporation and hydrogen is released. For example:

Hydrochloric acid	+	Iron	$\rightarrow$	Ferric chloride	+	Hydrogen
6 HCl	+	2 Fe	$\rightarrow$	2 $FeCl_3$	+	3 H_2

The hydrogen can be captured (pneumatically) and then detected with the oxyhydrogen test.
The less noble the metal is, the more violent the reaction. Furthermore, a strong acid etches nobler metals better than a weak acid. So, hydrochloric acid can etch metals such as magnesium, aluminum, and iron. For a reaction with gold, on the other hand, so-called “aqua regia” is required (a mixture of 75% concentrated hydrochloric acid and 25% concentrated nitric acid).
The etching of metals by acids was already used in the Middle Ages to decorate armor. Nowadays, etching is used both in arts and crafts and in industry. For example, copper plates are etched with dilute nitric acid.

Fig. 7.3.1: Dripping acid on iron
Picture of the chain by analogicus, 2018 freely available on Pixabay;
Picture of the dropper bottle by Birgit Lachner, 2019 (CC-0 1.0)

The lesson leaves open whether the learners check different acids with one type of metal or different metals with one type of acid. This variety need not be prevented, as it broadens the range of observations for the conclusions. However, the teacher should lead the lesson such that, at least in some groups, the difference between noble and base metals becomes clear. The choice of metals used in the lesson depends both on the school's supplies and on the safety aspects. The collection of hydrogen is initially dispensed with. If fast groups nonetheless arrive at the question of which gas was produced, a corresponding proof can be connected. Otherwise, this would be a topic for a follow-up lesson.

Determination of the objective (domain of the lesson):

The focus of this lesson is on the procedural domain. In particular, the independence of the learners in the field of planning and conducting investigations is to be promoted.

The four decision stages of the Differentiation Tool:

1. Selection of setting

The learners in our example are used to carrying out experiments in partner work, as this is how as many learners as possible come to action. The individual sub-tasks are always first worked on individually and then discussed with the partner. This ensures that all learners are cognitively involved in the classroom. If necessary, an agreement between the learners of a partner group must be reached. The topic of the lesson is usually covered at the end of grade 9 or at the beginning of grade 10. Learners usually find themselves together with a partner with whom learning can succeed.

2. Selection of the relative openness of the sub-phases

Figure 7.3.2 shows which degrees of IBL openness have been selected for the partner groups as examples. In our example, we have partner groups that work in the group 1 pattern and partner groups that work in the group 2 pattern. As Figure 7.3.2 illustrates, the *Orientation* phase is *opened* for everyone. The learners work out the phenomenon with the help of images (see Appendix 7.3.I). Subsequently, the learners of the partner groups in group pattern 1 select their question (sub-phase *Questioning*) from various possibilities (see Appendix 7.3.II). The degree of opening is *moderately opened*. Partner groups in group pattern 2 develop their question in an *opened* degree. Teacher assistance results from learner questions and is offered on-the-fly. Subsequently, the learners can – if necessary – check their research question with the help of the checklist for reviewing a question (see Appendix 7.3.III). The *Hypothesis Generation* sub-phase is *opened* for all partner groups. Again, there is a checklist for reviewing a hypothesis (see Appendix 7.3.IV). Furthermore, the teacher is available for on-the-fly assistance. The

Planning and Conducting Investigation sub-phase is *opened* for all partner groups. As an aid, the learners can look at all available materials and then independently select them, with support from the teacher if necessary. The *Data Interpretation* takes place in the partner groups in the group 1 pattern in a *closed* way. A table is provided for recording data (see Appendix 7.3.V). Partner groups in the group 2 pattern select a data representation with the support of the teacher, this phase is *moderately opened* for the partner groups in the group 2 pattern. The *Conclusion* is *opened* for all and is done in a whole-class conversation. The teacher offers support with targeted questions.

		0 closed	*1 moderately opened*	*2 opened*	*3 open*
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
Conceptualization	**Hypothesis Generation**	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a hypothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
Investigation	**Data Interpretation**	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	Learners develop their own conclusion

group 1

group 2

Teacher-directedness — Student-directedness

Fig. 7.3.2: Possible degrees of openness

3. Selection of sub-phases to be scaffolded to the next level

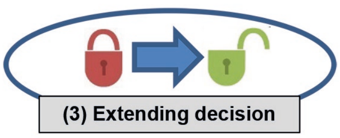


Figure 7.3.3 shows which sub-phases in this lesson are to be extended in their degree of openness.

In the sub-phase *Questioning,* the learners are scaffolded in the group 1 pattern to achieve the degree *opened*. The learners in the group 2 pattern should reach the degree *open* in this sub-phase. Likewise, in the sub-phase *Data Interpretation*, the learners are supported to achieve the next degree of openness. Learners in group pattern 1 are scaffolded to reach *moderately opened* and learners in the group 2 pattern to reach *opened*.

		0 *closed*	1 *moderately opened*	2 *opened*	3 *open*
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
	Hypothesis Generation	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a hypothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
	Data Interpretation	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	Learners develop their own conclusion

Teacher-directedness — Student-directedness

group 1 (orange) *group 2* (yellow)

Fig. 7.3.3: Extensions for the two example group patterns

4. Selection of methods for scaffolding

For the sub-phase *Questioning,* the checklist (see Appendix 7.3.III) was chosen as a support. However, learners in the group 2 pattern should also do without this checklist. In addition, the teacher is always available for help. In the *Data Interpretation* sub-phase, partner groups in the group 1 pattern are presented with some options for data collection for the present experiment (see Appendix 7.3.VI). In conversation with the teacher, the learners then select a justified type of presentation. Partner groups in the group 2 pattern receive help cards for support (see Appendix 7.3.VII).

Lesson plan

<table>
<tr><td>Grade: 9–10</td><td>Subject domain: Chemistry</td><td colspan="2">Topic: Metals react with hydrochloric acid</td><td>Duration: 90 min</td></tr>
<tr><td colspan="5">Prior knowledge:
Learners already know that:
▪ metals can be etched with hydrochloric acid;
▪ the less noble metals are, the more reactive they are with oxygen;
▪ the hydrogen produced in these reactions can be detected with the oxyhydrogen test.
Learners already be able to:
▪ formulate hypotheses in relation to questions;
▪ plan simple experiments to test their hypotheses.</td></tr>
<tr><td colspan="5">Driving question: The learners are inspired to engrave their name on a door sign by etching with acid. They should select a suitable metal or a suitable acid for this purpose.</td></tr>
<tr><td>Learning objectives: must be feasible to put into operation and measurable against the learning products</td><td>Teaching/learning material: reference material, physical or virtual materials and resources</td><td>Learning activity: a description of what learners do, including the instructional support they receive</td><td>Learning product: needs to reflect knowledge or skills included in the learning objectives and allow a flow of learning activities</td><td>Assessment (formative, peer, or summative): focused on learning products</td></tr>
<tr><td></td><td>Images (see Appendix 7.3.I)</td><td>Based on two images, the learners discuss the phenomenon whereby acids can etch metals. It is not yet clear whether this works for all metals.</td><td></td><td></td></tr>
<tr><td>Learners perform the sub-phases of an examination to investigate the reaction of various metals with hydrochloric acid or of different acids with a chosen metal.</td><td>Pool of possible questions (see Appendix 7.3.II)

Checklist for reviewing the question (see Appendix 7.3.III)</td><td>On the basis of the problem, the research question is formulated. In the group 1 pattern, the learners finish incomplete questions in partner work and select a question from various options (a checklist helps them). Learners in the group 2 pattern first formulate the question in individual work and then compare it with their partner. Agreement must be reached. The teacher provides help if necessary (on-the-fly scaffolding).</td><td>Research question</td><td>Observations in the classroom by the teacher; support if necessary, with the help of prompts.</td></tr>
</table>

		Suitable questions are: “Can dilute acids etch metals? Can hydrochloric acid etch all metals equally well? Can all acids etch aluminum equally well?”		
	Checklist for reviewing a hypothesis (see Appendix 7.3.IV)	The learners formulate a hypothesis in the form of an “If…, then…” statement. Again, first in individual work and then in coordination with the partner.	Hypothesis	Observations in the class-room by the teacher; sup-port if necessary, with the help of prompts.
	Required experimental material depending on the implementation (e.g., test tubes, Petri dishes, various metals such as magnesium tape, alumi-num foil, iron plate, cop-per sheet, silver sheet, stainless steel, acid, safety goggles)	Formulation of the implementation steps in partner work. Attention paid to the language used, compliance with the safety aspects and whether the hypothesis is tested. After the safety check by the teacher, the learners perform the experiment in pairs. The following experiments are possible: - change of metals with the same acid (no-ble and base metals) - change of acid with the same metal - change in the concentration of a particu-lar acid with the same metal.	Planned experiment	Observations in the class-room by the teacher; sup-port if necessary, with the help of prompts.
	Various forms of data presentation (see Appen-dix 7.3.VI) Help cards (see Appendix 7.3.VII)	Learners record their observations (a table is suitable). Transition from *closed* to *moderately opened*: learners in the group 1 pattern are presented with various options for data presentation in a short input and then have to decide on one in conversation with the teacher. Transition from *opened* to *open*: learners in the group 2 pattern receive help cards to help them choose the form of data presentation.	Data presentation	Observations in the class-room by the teacher; sup-port if necessary, with the help of prompts.
Students can make a reasoned decision as to	Blackboard text (see Ap-pendix 7.3.VIII)	In the classroom discussion, the observations are briefly mentioned and then discussed	Conclusion	

which metal or acids are suitable for etching and which are not.		together to determine possible conclusions. Subsequently, the initial question is answered, and technical applications are addressed.		
End of lesson: The lesson ends with a reflection on the IBL process and personal learning progress. If one or more groups work particularly fast, the follow-up question “Which gas is produced?” can be followed up here. Alternatively, this question can be discussed in plenary or in the following lesson after the conclusions.				

Appendix 7.3.I – Images for phase *Orientation*

Appendix 7.3.II – Pool of questions

Today we are dealing with the phenomenon that acids can etch metals. Complete the questions below and select one of the following questions for your investigation:

- Can dilute acids etch metals?
- Is knight's armor heavier than plastic armor?
- Are copper boards or plastic boards better suited for computer construction?
- Can hydrochloric acid etch ________________________________ equally well?
- Can ______________________________________ etch aluminum equally well?

Appendix 7.3.III – Checklist for reviewing a question

Checklist for reviewing a question:

- ☐ Does the question have anything to do with the main topic of current chemistry lessons?
- ☐ Does the question fit our problem?
- ☐ Is the question experimentally (at least in parts) verifiable, so that a rule can then be derived?

If you can't answer "yes" to all of these questions, it's not a suitable question. Please then modify the self-formulated question respectively select another question.

Appendix 7.3.IV – Checklist for reviewing a hypothesis

Checklist for reviewing a hypothesis:

- ☐ Is the hypothesis a possible answer to the question?
- ☐ Can you justify your hypothesis with your previous knowledge?
- ☐ Does the hypothesis indicate the expected result?
- ☐ Is the hypothesis in an if ... then... sentence formulated?

If you can’t answer “yes” to all of these questions, then you'll need to change or reformulate your hypothesis accordingly.

Appendix 7.3.V – Data collection table

For the example of hydrochloric acid with different metals, you can record your observations in the following table:

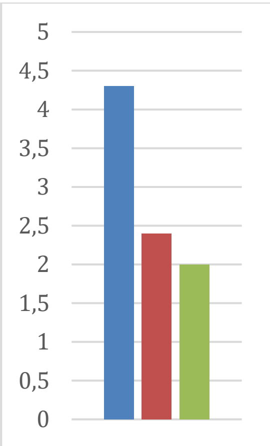
Hydrochloric acid + ...	Iron	Aluminum	Copper	Silver
				
				
				
 ***First remove the acid from the metal (wash off)!***				

Adjust the table according to the metals you selected. Or change them accordingly if the metal remains the same and the acid changes.

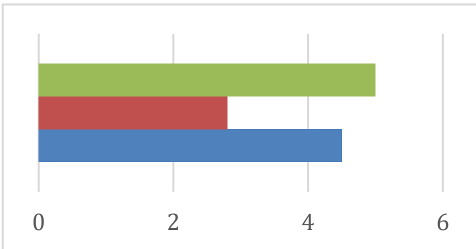
If you can’t observe anything in an area, put a line in the appropriate field.

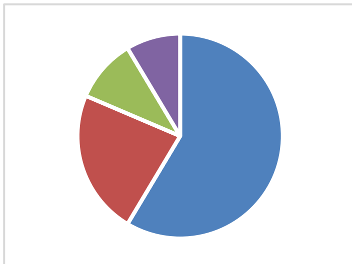
Appendix 7.3.VI – Various possibilities for data presentation

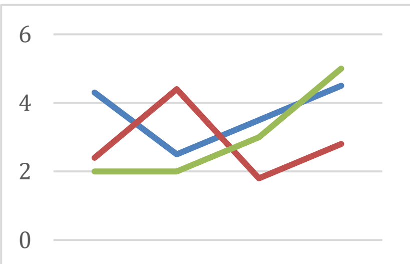
1. Look at the different ways to collect and present data and name them.
2. Consider what types of data the different presentation methods are suitable for.
3. Decide which type of data presentation is suitable for our experiment. Justify your decision.



	xxx	xxx	xxx	xxx
yyy				
yyy				
yyy				
yyy				







1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________

Appendix 7.3.VII – Help cards for selecting type of data collection

Help 1: Think about what types of data presentation you know. Don't limit your thoughts to chemistry lessons.

Help 2: For the types of data presentation from 1, think about which areas of application make sense in each case.

Help 3: Do you have more data in the form of numbers or in the form of text in the experiment here?

Help 4: Graphs are suitable for data in the form of numbers, tables and bulleted lists are suitable for data in the form of text.

Appendix 7.3.VIII – Black board text for conclusion

The less noble a metal is, the better it reacts with hydrochloric acid. Magnesium reacts most violently, then come aluminum and iron. Copper and silver are not etched at all.
The stronger an acid, the better it reacts with a metal. Carbonic acid hardly etches iron, nitric acid already better and hydrochloric acid works best.
The reaction of metals and hydrochloric acid produces a gas.

Reaction scheme (example):

Hydrochloric acid + Iron → Ferric chloride + ???

Reaction equation (example):

$HCl + Fe \rightarrow FeCl_3 + ???$

7.4 The role of soot in global warming (Biology/Science, suitable for grades 9–10)

Factual information

Topics related to global warming have most recently become more relevant and important for young people since the "Fridays for Future" movement. They are familiar with problems such as the progression of the anthropogenic greenhouse effect through the emission of greenhouse gases and the associated global warming.

Less well-known is the role of soot, fine black particles produced during the combustion of fuels, coal, or wood. Soot particles are also produced during bushfires or in industry. These particles are deposited as dark veils on the snow and ice surfaces in Antarctica, in the Arctic, and on glaciers. As a result, snow and ice masses reflect less sunlight – instead, they absorb it and their reflectivity decreases. This leads to heating and so to faster melting (Nestler, 2019; Osterkamp, 2022).

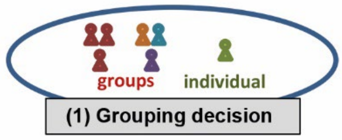
Nestler, R. (2019). Ruß lässt Gletscher schneller schmelzen. https://www.wienerzeitung.at/nachrichten/wissen/natur/2002291-Russ-laesst-Gletscher-schneller-schmelzen.html [last access: 10.03.2022].
Osterkamp, J. (2022). Umweltverschmutzung verschlimmert Schneeschmelze in der Antarktis. https://www.spektrum.de/news/antarktis-umweltverschmutzung-beschleunigt-schneeschmelze/1990678 [last access: 10.03.2022].

Determination of the objective (domain of the lesson):

In this lesson, the focus is on the conceptual domain. The development of an experiment to detect the absorption of dark surfaces and their warming serves to transfer knowledge to global phenomena and consequences of human action. The learners should get to know, understand, and critically reflect on the complex interrelationships of climate change. Transference to other areas of life should also be part of the lessons.

The four decision stages of the Differentiation Tool:

1. Selection of setting



The learners are divided into groups of two and three learners by the teacher. Both homogeneous and heterogeneous groups emerge. Homogeneous groups can choose the right worksheet according to their performance level. In more heterogeneous groups, higher-performing learners can coach the weaker ones. The choice of the worksheet takes place in a democratic way in the heterogeneous groups.

2. Selection of the relative openness of the sub-phases

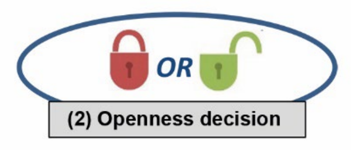


Figure 7.4.1 shows the degrees of IBL openness selected for the groups (group 1 chooses worksheet 1 and group 2 chooses worksheet 2). The different colours represent the different example groups.

At the beginning of the lesson, the teacher introduces learners to a current problem with the help of headings. Figure 7.4.1 shows that the *Orientation* phase is *closed* for all groups. After the *Orientation* phase, learners are divided into groups and select worksheet 1 or worksheet 2 within their group.

While the group receives a pre-formulated question (*closed*) with worksheet 1, the group with worksheet 2 is obliged to formulate a suitable question with the help of the info text on the worksheet (*opened*). The groups receive support in the form of on-the-fly feedback from the teacher. To generate hypotheses, group 1 selects from several hypotheses (*moderately opened*), but also has the possibility to formulate its own hypothesis (transition to *opened*). In principle, it is also possible to select several hypotheses and later test them experimentally. The group with worksheet 2 generates its own hypothesis for the question (*open*). If they need help, they will receive support from the teacher in the form of on-the-fly feedback. The sub-phase *Planning and Conducting Investigation* is *moderately opened* in group 1. The learners later receive different experimental setups on help cards as scaffolds. However, depending on the task, they must choose the most suitable setup for their hypothesis from among different materials (which already represents the next degree of openness, see the *extending decision* below). Group 2, with worksheet 2, independently selects suitable material for the *Planning and Conducting Investigation* sub-phase (*open*). As support, options of materials can be viewed at the teacher's table. For *Data Interpretation*, a ready-made table is available to group 1 with worksheet 1, in which the learners decide which observation or measurement is entered (*closed*). Group 2 with worksheet 2 finds a blank table on its worksheet (*moderately opened*). For both groups, the *Conclusion* must first be written (*opened*) by answering questions and then discussed in plenary.

		0 *closed*	*1* *moderately opened*	*2* *opened*	*3* *open*
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
Conceptualization	**Hypothesis Generation**	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a hypothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
Investigation	**Data Interpretation**	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	Learners develop their own conclusion

group 1

group 2

Teacher-directedness — Student-directedness

Fig. 7.4.1: Possible degrees of openness; group 1 works with worksheet 1 and group 2 works with worksheet 2

3. Selection of sub-phases to be scaffolded to the next level

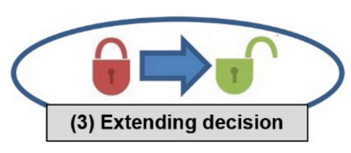
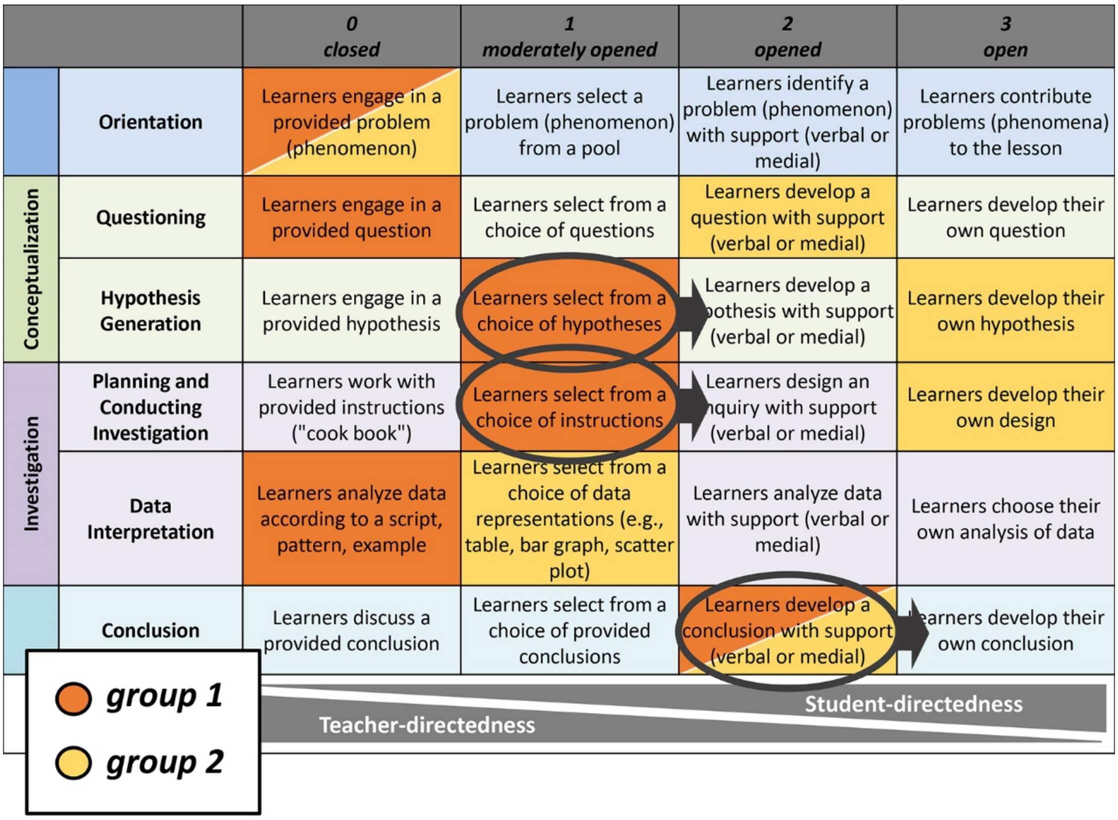


Figure 7.4.2 illustrates the sub-phases which are extended in their openness in this example.

The learners in the *moderately opened* sub-phase *Hypothesis Generation* (group 1) are supported in achieving the next degree of openness (*opened*). In the sub-phase *Planning and Conducting Investigation*, this is done analogously. In the sub-phase *Conclusion*, group 2 is to be reaffirmed to consider its own conclusions.



		0 closed	1 moderately opened	2 opened	3 open
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	Questioning	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
Conceptualization	Hypothesis Generation	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a pothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	Planning and Conducting Investigation	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an nquiry with support (verbal or medial)	Learners develop their own design
Investigation	Data Interpretation	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	earners develop their own conclusion

Fig. 7.2.4: Extensions for the two example groups

4. Selection of methods for scaffolding

When creating hypotheses, group 1 is given a selection of hypotheses and the option to come up with its own formulation.

For the sub-phase *Planning and Conducting Investigation*, group 1 has help cards with pictures (experimental setups) to get suggestions if necessary.

Group 2 is supported in the sub-phase *Conclusion* with verbal aids if necessary (Help 1: “Summarize your result first.” Help 2: “Was your hypothesis proven/refuted?” Help 3: “Has the question been answered now?” Help 4: “What does your result mean in terms of climate change and sustainable action?”).

Lesson plan

Grade: 9–10	**Subject domain:** Biology/Science	**Topic:** The role of soot in global warming		**Duration:** 90 min
Prior knowledge: Learners already know that: ▪ the natural greenhouse effect makes the earth habitable and manageable; ▪ the anthropogenic greenhouse effect promotes climate change; ▪ global warming is melting the polar ice caps; ▪ global warming has far-reaching ecological and economic consequences. Learners are already able to: ▪ distinguish dependent and independent variables; ▪ assign control and test trials; ▪ write protocols.				
Driving question: The learners investigate how the deposition of soot particles on glaciers or ice and snow masses can have an effect.				
Learning objectives: must be feasible to put into operation and measurable against the learning products	**Teaching/learning material:** reference material, physical or virtual materials and resources	**Learning activity:** a description of what learners do, including the instructional support they receive	**Learning product:** needs to reflect knowledge or skills included in the learning objectives and allow a flow of learning activities	**Assessment (formative, peer, or summative):** focused on learning products
Learners recognize a problem in the deposition of soot on glaciers and on Arctic and Antarctic ice. Learners plan an experiment and carry it out.	Image with headlines (Appendix 7.4.I)	The teacher asks “What do bushfires, smoking chimneys and cruise ships have in common?” The teacher projects different headlines, one after the other, and learners discuss how soot particles darken snow and ice surfaces.	Problem	
	Worksheet 1 or 2 (Appendices 7.4.III and 7.4.IV)	After the learners have been divided into groups of two and three, they opt for worksheet 1 or worksheet 2, depending on their level of performance (teacher provides orientation if necessary). In the introduction, they read the short text that is on both worksheets. The groups with worksheet 1 (group 1) receive a given	Research question	Observations in the classroom; if necessary, verbal support by the teacher.

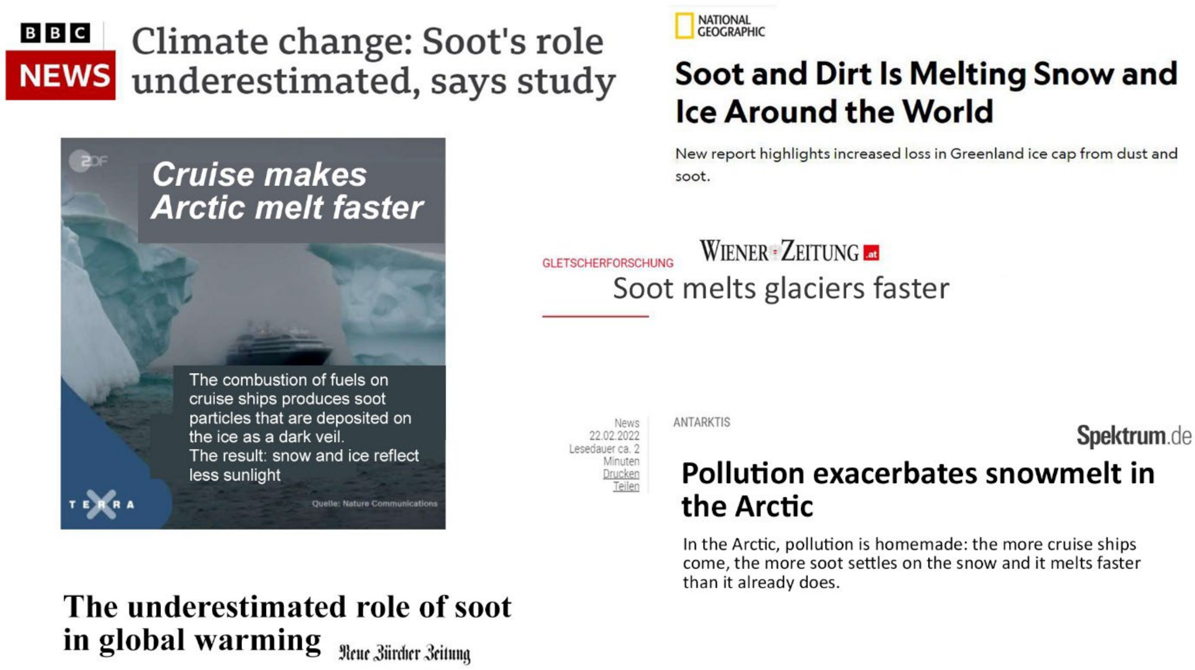
		question, the groups with worksheet 2 (group 2) consider a suitable question. The teacher is available to support them with prompts.		
	Worksheet 1 or 2 (Appendixes 7.4.III and 7.4.IV)	The learners with worksheet 1 select one or more hypotheses from a given set and have the opportunity to formulate their own hypotheses. The learners with worksheet 2 independently formulate one or more suitable hypothesis(-es).	Hypothesis	Observations in the classroom; if necessary, verbal support by the teacher.
	Help cards: Pictures with possible experimental setup (Appendix 7.4.II) Material: - ice cubes - scissors - adhesive tape - cup - black paper - white paper - scales - black ink - lamp (sun) - stopwatch - thermometer	All learners define the dependent and the independent variables after establishing their hypotheses. The learners with worksheet 1 plan an experiment that fits the selected hypothesis. They select the material for experimentation from a set of materials. Help cards are used as scaffolds that show possible experimental setups. The learners with worksheet 2 plan an experiment on the selected hypothesis. If they have problems, then they can view the set of materials on the teacher's table. On the worksheet, the learners document the structure/sequence of their test trial and then consider a control trial for their experiment. Here, the teacher is available to provide support if required. There is space on the worksheet to outline the planned experimental trial before and after the experiment.	Planned experiment	Observations in the classroom; if necessary, verbal support by the teacher. Worksheets can be used for diagnostics.
		The learners with worksheet 1 record their data in a table.	Data presentation	Observations in the classroom; if necessary, verbal support by the teacher.

		Learners with worksheet 2 will find an empty table on their worksheet.		
	Simulation on the retreat of the glacial ice of Columbia Glacier: https://earthengine.google.com/timelapse Simulation of the retreat of the Greenland ice: https://www.zeit.de/wissen/umwelt/2019-06/klimawandel-treibhausgaseffekt-erderwaermung-folgen Aerial view of Okjökull Glacier (Iceland) in 1986 and 2019: https://www.stuttgarter-zeitung.de/inhalt.klimawandel-die-grossen-gletscher-schmelzen-dahin.f2148208-a5bf-47b8-9306-0a87b56551c5.html	In the first part of the conclusion, all learners should summarize and explain their results. They then explain whether their hypothesis has been confirmed. Finally, the learners consider conclusions regarding global warming and where the color of the surface and its associated warming could possibly still play a role. In the classroom discussion, the entire process is reflected upon and the ideas from the conclusions are discussed. The teacher can ask supportive questions, such as: “In what color car would you rather ride on a hot summer day: black or white?” “What color should houses in hot or cold areas of the Earth be?” ”What color is suitable for solar panels?”, etc. To illustrate the role of (white) ice surfaces, the teacher concludes by showing satellite images of glaciers or Arctic ice over time and stimulating a discussion. The learners realize that due to the melting of the ice surfaces, the “bright” surfaces become darker and a negative feedback loop is created. The less ice there is, the less reflection and the stronger the (global) warming.	Conclusion	

Possible follow-up topics:

- Effects of global warming on living things in the Arctic and Antarctic → Biology
- Effects of global warming on global currents (Gulf Stream) → Geography
- Albedo effect → Physics

Appendix 7.4.I – Image with headlines


BBC NEWS

Climate change: Soot's role underestimated, says study

NATIONAL GEOGRAPHIC

Soot and Dirt Is Melting Snow and Ice Around the World

New report highlights increased loss in Greenland ice cap from dust and soot.

ZDF

Cruise makes Arctic melt faster

The combustion of fuels on cruise ships produces soot particles that are deposited on the ice as a dark veil.
The result: snow and ice reflect less sunlight

TERRA X

Quelle: Nature Communications

GLETSCHERFORSCHUNG

WIENER ZEITUNG .at

Soot melts glaciers faster

News
22.02.2022
Lesedauer ca. 2 Minuten
Drucken
Teilen

ANTARKTIS

Spektrum.de

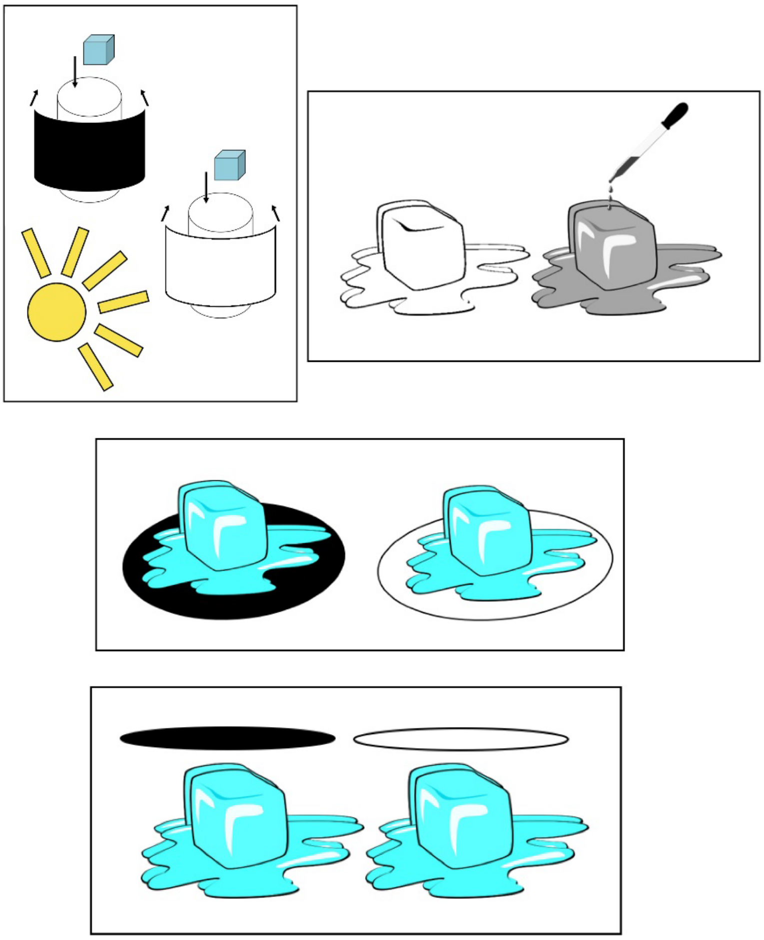
Pollution exacerbates snowmelt in the Arctic

In the Arctic, pollution is homemade: the more cruise ships come, the more soot settles on the snow and it melts faster than it already does.

The underestimated role of soot in global warming

Neue Zürcher Zeitung

Appendix 7.4.II – Help cards



The role of soot in global warming

You already know that the burning of fossil fuels releases greenhouse gases, which in turn contribute to global warming.

Less well-known is the role of soot, fine black particles produced during the combustion of fuels, coal, or wood. Soot particles are also produced during bushfires or in industry. These particles are deposited as dark veils on the snow and ice surfaces in Antarctica, in the Arctic, and on glaciers.

Glacier – Image: *anncapictures*, 2016, available on Pixabay (License for free commercial use)

Research question:

Do dark surfaces lead to warming and thus to faster melting of ice?

Select one (or more) hypothesis(es) that you would like to test:

- ☐ Hypothesis 1: If there is a black layer under ice, then it melts faster.
- ☐ Hypothesis 2: The polluted ice means that the white animals of the Arctic can no longer camouflage themselves.
- ☐ Hypothesis 3: When ice is darkly coated, it melts faster.
- ☐ Hypothesis 4 (for your own idea):

____

____

According to our hypothesis, the dependent variable is:

____

and the independent variable is:

____

Material (select the material you need to test your hypothesis):

- ☐ ice cubes
- ☐ scissors
- ☐ adhesive tape
- ☐ cup
- ☐ black paper
- ☐ white paper
- ☐ scales
- ☐ black ink
- ☐ lamp (sun)
- ☐ stopwatch

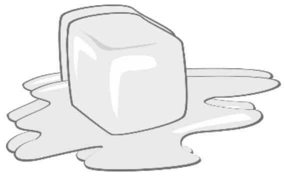
Test trial: Formulate the test trial for your chosen hypothesis. Important: only one dependent vari-able may be changed per trial.

____

____

____

Control trial: Summarize how to control your test trial.



____

____

____

Here is space for a sketch or a photo of your approaches before and ...	…after the attempt!

Record what the ice cubes look like after 10 minutes and the time after which the first ice cube melted:

	Control trial	Test trial	Optional test trial (2)
Minute: 10			
Minute: ________			

Data evaluation and conclusion:

1. Summarize your result.
2. Explain if you were able to confirm your hypothesis(-es) or had to discard them.
3. What does your experiment mean to you? What conclusions can you draw? Do you benefit from the new knowledge?

1. ____

____

2. ____

3. ____

____

____

<u>The role of soot in global warming</u>

You already know that the burning of fossil fuels releases greenhouse gases, which in turn contribute to global warming.

Less well-known is the role of soot, fine black particles produced during the combustion of fuels, coal, or wood. Soot particles are also produced during bushfires or in industry. These particles are deposited as dark veils on the snow and ice surfaces in Antarctica, in the Arctic, and on glaciers.

Glacier – Image: *anncapictures*, 2016, available on Pixabay (License for free commercial use)

Research question:

____

____

Formulate one (or more) hypothesis(-es) as to how you think your research question could be answered.

☐ Hypothesis 1:

____

____

☐ Hypothesis 2:

____

____

According to our hypothesis, the dependent variable is:

____

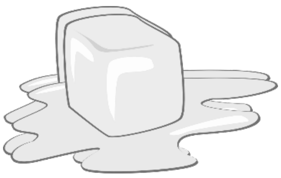
and the independent variable is:

____

Material (what material do you need to test your hypothesis?):

Test trial: Formulate the test trial for your chosen hypothesis. Important: Only one dependent variable may be changed per trial.

Control trial: Summarize how to control your test trial.



Here is space for a sketch or a photo of your approaches before and ...	…after the attempt!

Record (consider which notes, numbers, data, etc. you need for the evaluation):

Data evaluation and conclusion:

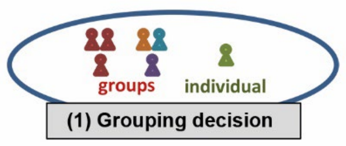
7.5 Melting rate of ice cubes (Physics, suitable for grades 6–7)

Determination of the objective (domain of the lesson):

The lesson focuses on the conceptual domain. The key concepts are heat transfer and heat capacity. In this case, learners can learn that melting of ice requires energy that is transferred by radiation and conduction (convection is not central in this case), differently colored surfaces absorb different amounts of heat radiation, and the mass of ice cubes affects the melting rate (heat capacity).

The four decision stages of the Differentiation Tool:

1. Selection of setting



Learners form heterogenous groups where the higher-performing learners can support their lower-performing peers. The teacher knows that some learners need more practice in choosing a suitable experimental setting (design inquiry), while others can create their own setting. All learners who need a lot of support in design inquiry are placed in such groups, but these groups may also include learners who are more advanced in design inquiry. The groups may also be heterogenous in ways other than design inquiry. However, the ability to understand the experimental setting is crucial when the teacher forms groups.

2. Selection of the relative openness of the sub-phases

Figure 7.5.1 shows the level of openness of the sub-phases of IBL that the groups of learners follow. As in all the example lesson plans presented in this book, the different colors represent two different groups to which learners may belong.

The figure shows that in this lesson, all groups of learners can engage with a given problem (*closed*). In addition, the teacher forms a research question (*closed*) when they initially discuss with learners about the melting of ice. Regarding *Hypothesis Generation*, some groups can select an appropriate hypothesis from a list (*moderately opened*) and some groups can formulate hypotheses with support (*opened*). In terms of *Planning and Conducting Investigation*, some groups need provided instruction (*closed*) when others can design inquiry with support (*opened*). In the last two sub-phases, all groups are at the same level. They can interpret data without support (*open*) and make conclusion with support (*opened*).

		0 *closed*	1 *moderately opened*	2 *opened*	3 *open*
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) froma pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
Conceptualization	**Hypothesis Generation**	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a hypothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
Investigation	**Data Interpretation**	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	Learners develop their own conclusion

group 1
group 2

Teacher-directedness — Student-directedness

Fig. 7.5.1: Level of openness for the two example groups

3. Selection of sub-phases to be scaffolded to the next level of openness

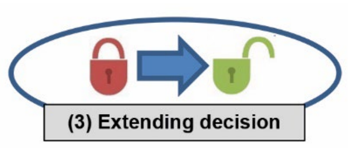


Figure 7.5.2 illustrates the sub-phases in which learners are to be supported by means of scaffolds (to be defined in the next decision stage) to reach the next level of openness.

In the sub-phase *Hypothesis Generation*, some groups need support to move from the level *moderately opened* to *opened* and others from *opened* to *open*. In the sub-phase *Planning and Conducting Investigation*, part of the groups will be supported from *closed* to *moderately opened*, while others move from *opened* to *open*.

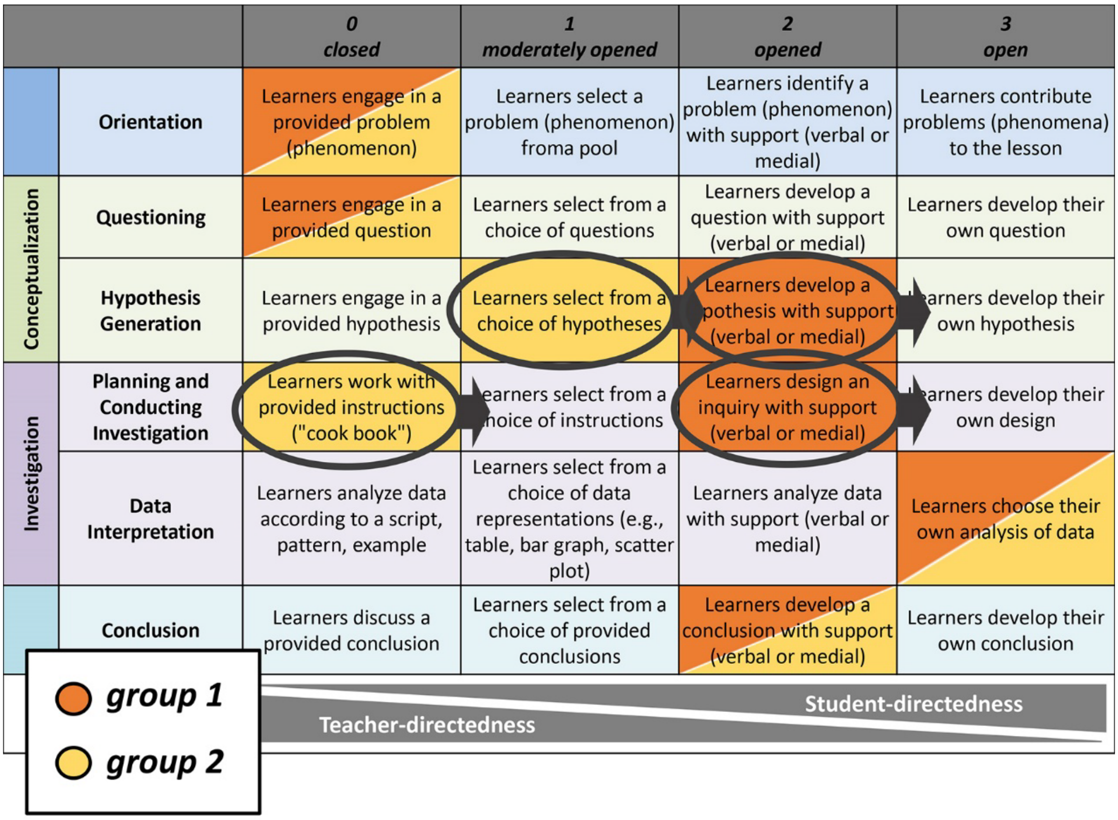


Fig. 7.5.2: Extensions for the two example groups

4. Selection of methods for scaffolding

For the sub-phase *Hypothesis Generation*, the method of scaffolding chosen is to provide hints to learners so they can formulate their hypothesis. Groups who move from *moderately opened* to *opened* are provided with all the words they need to write their hypothesis. Other groups who move from *opened* to *open* are provided with only the general hint to keep in mind the independent and dependent variables.

For the sub-phase *Planning and Conducting Investigation*, some groups (those going from *closed* to *moderately opened*) are provided with pictorial design alternatives, which visually helps them to consider different possible designs (see Appendix 7.5.II). In addition, the teacher gives the necessary support on-the-fly. Groups who move from *opened* to *open* are supported on-the-fly when they need guidance.

Lesson plan

<table>
<tr><td>Grade: 6–7</td><td>Subject domain: Physics</td><td colspan="2">Topic: Melting rate of ice cubes</td><td>Duration: 2 x 45 min</td></tr>
<tr><td colspan="5">Prior knowledge:
Learners:
▪ know that water melts from ice to liquid water when heated;
▪ probably know that bigger pieces of ice melt more slowly than smaller ones.</td></tr>
<tr><td colspan="5">Driving question: Learners are engaged to think how to make a piece of ice melt as quickly as possible outdoors in the spring when sun is warming.</td></tr>
<tr><td>Learning objectives: must be feasible to put into operation and measurable against the learning products</td><td>Teaching/learning material: reference material, physical or virtual materials and resources</td><td>Learning activity: a description of what learners do, including the instructional support they receive</td><td>Learning product: needs to reflect knowledge or skills included in the learning objectives and allow a flow of learning activities</td><td>Assessment (formative, peer, or summative): focused on learning products</td></tr>
<tr><td rowspan="2">Plan and study the factors that affect the melting rate of an ice cube</td><td></td><td>The teacher discusses whether the learners have seen anyone, such as the caretaker of a building, spreading out piles of snow on the asphalt in the winter or spring (the latter works in Finland). Why do they do so? Next, the teacher engages the learners to consider how they could make an ice cube melt outside as quickly as possible. The teacher continues the discussion so far that several possible factors affecting the melting rate of an ice cube emerge. The teacher forms research question with the learners: what factors affect the melting rate of ice cubes outdoors?</td><td>Research question</td><td>This is a teacher-led phase but through the discussion, the teacher gets information about the learners' thinking for later guidance; so, in that sense, formative assessment is involved.</td></tr>
<tr><td>Worksheet (Appendix 7.5.I)</td><td>Groups moving from moderately opened to opened, are provided with all the words they need to write their hypothesis. Other groups, moving from opened to open, are provided only with the general hint to keep in mind the independent and dependent variables.</td><td>Hypothesis</td><td></td></tr>
</table>

	Laboratory equipment Pictorial alternatives (Appendix 7.5.II)	From *closed* to *moderately opened*: Learners are provided with pictorial design alternatives, which visually helps them to consider different options (see Appendix 7.5.II). In addition, the teacher gives the necessary support on-the-fly. The teacher guides learners to select appropriate design if needed. Learners conduct the experiment using the selected plan and materials given by teacher (ice cubes, heat lamps, surface materials, timer…). They measure the melting time of ice cubes. From *opened* to *open*: Learners develop their own experimental design for the hypothesis of their choice. Learners can see the equipment and they write down their plan. The teacher asks the learners to measure the time so that the different factors studied can be compared between different groups. The teacher gives on-the-fly support when needed during the planning and the experiment.	Experimental design	In terms of formative assessment, the teacher provides on-the-fly support when learners need help.
		Learners keep a record of the melting times during the experiment in a table.	Table completed	
	Quiz for data interpretation and conclusion (Appendix 7.5.III)	Learners conclude their experiment by interpreting melting times. To do so they respond to certain questions.	Quiz responses	
Understand some theory behind the melting of ice cubes in different circumstances		Learners can read some theory about the factors that affect the melting of ice cubes and/or the teacher can discuss the theory when closing out the lesson.		
Closing: The teacher leads the whole class in discussion and reflection about the experiment, its results and conclusions.				

Appendix 7.5.I – Generating hypothesis

From moderately opened to opened

Your research question is: What factors affect the melting rate of ice cubes outdoors?

One possible factor we discussed is the color of the surface under the ice cube.

Formulate below your research hypothesis using the predefined terms and conditionals:

than / placed in sunlight / melts faster / an ice cube / on a black surface / on a white surface

____

From opened to open

Your research question is: What factors affect the melting rate of ice cubes outdoors?

We discussed many possible factors. You can select, as a group, one factor you want to study.

Formulate your research hypothesis below. Make sure to include *the independent variable* (e.g., the color of surface, size of ice cubes, or placement in sunlight/shade) and *order of melting of ice cubes*:

____

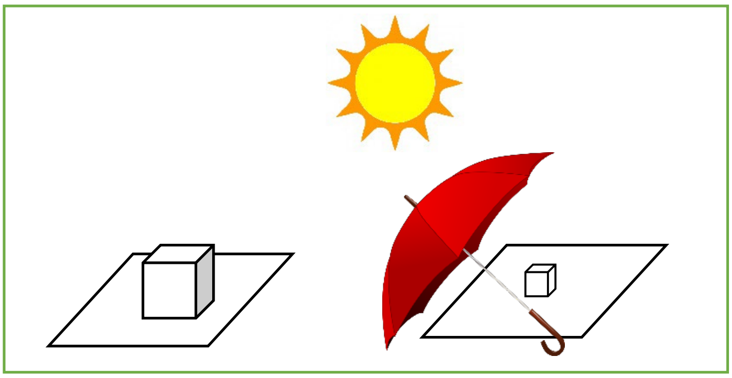
Appendix 7.5.II – Pictorial alternatives to select an appropriate experimental design

Closed to moderately opened

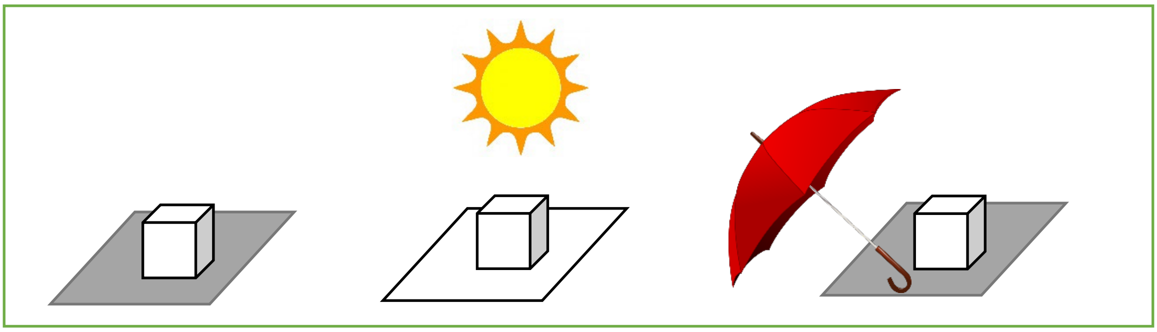
(Using the images below and similar other pictures, it is possible to form other hypotheses (e.g., size of ice cubes and placement in sunlight/shadow) as well, but here only the effect of surface color is presented as an example.)

You need to select which of the following designs would be better to study the effect of ground color.

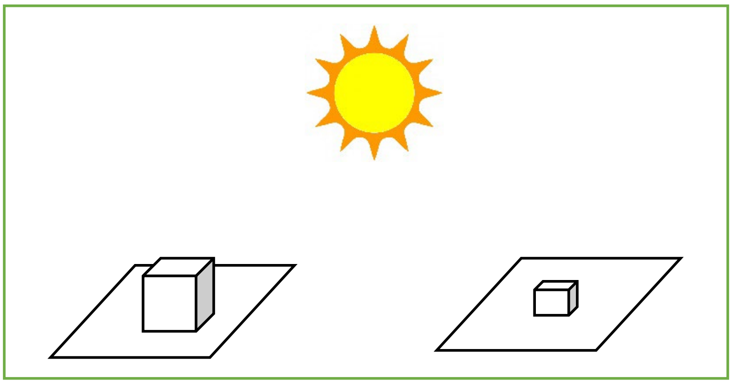
A) A big ice cube in sunlight and a small one in the shade. Which one melts first?



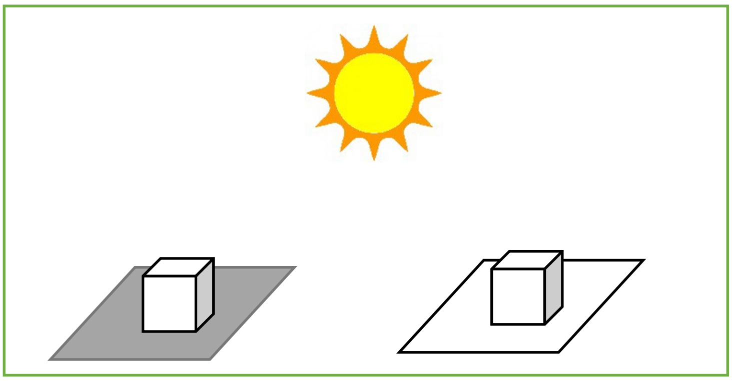
B) Same-sized ice cubes in three different conditions. One on a black surface in the sun, another on a white surface in the sun, and a third on a black surface in the shade. Which of the ice cubes melts first?



C) A big ice cube and a small one in the sun. Which one melts first?



D) The same-sized ice cubes in the sun, one on a black surface and the other on a white surface. Which one melts first?



Opened to open

Learners develop their own experimental design for the hypothesis of their choice. Learners can see equipment (e.g., heat lamps, surface materials, and timer) and they write down their plan. The teacher asks learners to measure the time so that different factors studied can be compared between different groups. Teacher gives on-the-fly support when needed during planning and conducting of the experiment.

Appendix 7.5.III – Quiz for data interpretation and conclusion

You studied the melting of ice cubes under certain conditions. Has your hypothesis been confirmed or rejected? Please explain.

Confirmed, because ____

____

____

Rejected, because ____

____

____

7.6 Heat and temperature (Physics, suitable for grade 9)

Determination of the objective (domain of the lesson):

The lesson focuses on the conceptual domain. The emphasis of the lesson is on understanding the natural phenomenon of heat transfer, the concept of specific heat capacity, and the law (equation) that describes the relationship between the change in temperature and the specific heat capacity. Therefore, the sub-phase *Conclusion* takes up a lot of space in this lesson.

The four decision stages of the Differentiation Tool:

1. Selection of setting

Learners form homogeneous groups so that they receive tasks of an appropriate level of complexity for all the members of the group. The learning objectives are the same for all learners in the groups. However, the level of support is different.

2. Selection of the relative openness of the sub-phases

Figure 7.6.1 shows the level of openness of the IBL sub-phases that each group of learners encounters. The different colors represent two different groups to which learners may belong, as in all the example lesson plans in this book.

According to Figure 7.6.1, all groups of learners can engage with the problem and they can formulate research questions with support, mainly verbal, in the form of on-the-fly feedback. Regarding *Hypothesis Generation*, some groups can select an appropriate hypothesis from a list and some groups can formulate hypotheses with support (see material below). Finally, all groups of learners are at the same level of openness in the next three sub-phases. Specifically, learners can select an experimental procedure to follow during their investigation, analyze the data collected, and reach a conclusion with support.

		0 *closed*	1 *moderately opened*	2 *opened*	3 *open*
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
Conceptualization	**Hypothesis Generation**	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a hypothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
Investigation	**Data Interpretation**	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	Learners develop their own conclusion

group 1
group 2

Teacher-directedness **Student-directedness**

Fig. 7.6.1: Level of openness for the two example groups

3. Selection of sub-phases to be scaffolded to the next level of openness

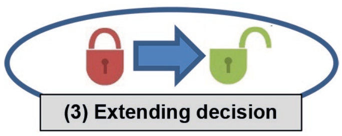


Figure 7.6.2 illustrates the sub-phases in which learners are to be supported by means of scaffolds (to be defined in the next decision stage) to reach the next level of openness.

Learners in the *moderately opened* level in the sub-phase *Hypothesis Generation* will be supported to move to the next level of openness, meaning the *opened* level, and learners in the *opened* level will be supported to move to the *open* level. Regarding the sub-phase *Planning and Conducting Investigation*, all learners will be supported to move to the next level of openness, meaning from the *moderately opened* to the *opened* level.

		0 *closed*	1 *moderately opened*	2 *opened*	3 *open*
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
Conceptualization	**Hypothesis Generation**	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a hypothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
Investigation	**Data Interpretation**	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	Learners develop their own conclusion

Teacher-directedness — Student-directedness

group 1
group 2

Fig. 7.6.2: Extensions for the two example groups

4. Selection of methods for scaffolding

For the sub-phase *Hypothesis Generation*, the method of scaffolding chosen is to provide hints so learners can formulate their own hypothesis. In the first group of learners (being supported to go from the *moderately opened* to the *opened* level), the hint provides all the necessary structural components for the formulation of a hypothesis in the form of an “If…, then…” statement. In the other group of learners (*opened* to *open* level), the hint provides only the main structural components for hypothesis formulation, namely the independent and dependent variables. For the sub-phase *Planning and Conducting Investigation*, help cards have been selected as the scaffolding method to help all groups of learners design their inquiry in a more open way (see Appendix 7.6.II).

Lesson plan

<table>
<tr><td>Grade: 9</td><td>Subject domain: Physics</td><td colspan="2">Topic: Heat and temperature</td><td>Duration: 80 min</td></tr>
<tr><td colspan="5">Prior knowledge:
Learners are familiar with the following:
a material changes its temperature when heat is supplied;
the temperature of a material is measured with different types of thermometers;
the units of heat measurement are the Joule and the calorie (1 cal = 4.2 Joule);
the mass of a liquid and the amount of heat supplied to the liquid affect the rate of the change in its temperature (previous inquiries).</td></tr>
<tr><td colspan="5">Driving question: Learners are prompted to think about how the way of cooking may affect the preparation time of food.</td></tr>
<tr><td>Learning objectives: must be feasible to put into operation and measurable against the learning products</td><td>Teaching/learning material: reference material, physical or virtual materials and resources</td><td>Learning activity: a description of what learners do, including the instructional support they receive</td><td>Learning product: needs to reflect knowledge or skills included in the learning objectives and allow a flow of learning activities</td><td>Assessment (formative, peer, or summative): focused on learning products</td></tr>
<tr><td rowspan="2">Conduct an investigation to identify the relationship between the change in temperature of a material and the type of the material.</td><td>Worksheet (Appendix 7.6.I)</td><td>Learners read an argument between two chefs and, based on the disagreement, they generate a research question to guide their investigation.</td><td>Research question</td><td>Guiding questions to help learners generate research questions about the type of liquid (on-the-fly feedback).</td></tr>
<tr><td>Worksheet (Appendix 7.6.I)</td><td>Learners formulate a hypothesis in the form of an “If…, then…” statement, indicating whether they believe that the type of liquid can affect the rate of temperature change.
From moderately opened to opened: some groups of learners make use of predefined terms for hypothesis formulation. All the terms needed for hypothesis formulation are provided.
From opened to open: some groups of learners formulate their hypothesis using fewer predefined terms.</td><td>Hypothesis</td><td></td></tr>
</table>

	Laboratory equipment Help cards (Appendix 7.6.II)	From *moderately opened* to *opened*: Learners are offered equipment and materials to plan an experimental procedure for collecting data to test their hypothesis. Learners are provided with help cards to support them in designing a valid experiment. They use the help cards at their own will. The teacher tracks the number of cards each group uses.	Experimental design	The teacher will be able to assess learners' readiness to conduct experiments in an opened form by counting the number of help cards used. If learners use all the help cards, then they are not yet ready.
		Learners keep a record of the data collected during the experiment in a table.	Table completed	
		Learners create a data graph of the rate of change in temperature of the liquids by displaying the measurements of time on the horizontal axis and the measurements of the liquids' temperatures on the vertical axis.	Data graph	
	Quiz for data interpretation and conclusion (Appendix 7.6.III)	Learners conclude their experiment by interpreting the curves on the data graph. To do so they respond to certain questions.	Quiz responses	Direct instruction on how to interpret the data graph is provided to the learners who have difficulties in doing so. For example, the rate of change of a quantity is related to the slope of the curve of that quantity when represented over time. The greater the slope of the curve, the greater the rate of change of the quantity.

Define the concept of the specific heat capacity.	Appendix (7.6.IV)	Learners read some theory about the concept of specific heat capacity and then they argue for choosing a cooking pot to prepare the food more quickly.	Written argument	Learners' final argument is used for summative or formative assessment.
Closing: The lesson closes with a reflection on the inquiry-based learning process.				

Appendix 7.6.I – Chefs' argument

Do you believe there is a difference between the rate of change in temperature of the two liquids and if so, which of the two do you think will heat up faster?

____

____

Formulate a research question to guide your experimentation regarding the chefs' argument:

____

[1]Formulate your research hypothesis below using the predefined terms and conditionals:
If / then / changes / remains the same / is different / the type of liquid / the rate of change in temperature

____

[2]Formulate your research hypothesis below. Make sure to include the terms *type of liquid* and *rate of change in temperature*:

____

[1] Moderately opened to opened
[2] Opened to open

Appendix 7.6.II – Help cards for the design of a valid experiment

Help card 1: Which of the following variables should you consider when designing your experiment?

- Liquid's mass
- Type of liquid
- Rate of heat supply
- Liquid's temperature

Help card 2: Which of the following variables should you keep constant during the experiment?

- Type and mass of the liquid
- Temperature and mass of the liquid
- Mass of the liquid and rate of heat supply

Help card 3: Which variable should you change in your experiment (independent variable)?

- Liquid's mass
- Type of liquid
- Rate of heat supply

Help card 4: Which variable should you observe/measure in your experiment (dependent variable)?

- Liquid's mass
- Liquid's temperature
- Type of liquid
- Rate of heat supply

Help card 5: In order to design a valid experiment, you must **keep constant** the **mass of the liquids**.
The variable you need to **change** is the **type of liquid**.
So, put the same amount of liquids (water and oil) in two containers.
The rate of **heat supply** must also remain **constant**.
As you supply heat to the containers, you must **record** the **temperature of each liquid over time**.

Appendix 7.6.III – Quiz for data interpretation and conclusion

1. Based on the data graph you drew, which liquid heats up faster?
   - The water
   - The oil
   - Both liquids heat up at the same rate

2. Has your hypothesis been confirmed or rejected? Please explain.

Confirmed, because ____

____

____

Rejected, because ____

____

____

3. What advice could you give to the two chefs about their decision on the side dish of their main course?

____

____

____

____

Appendix 7.6.IV – Final argument

The variable that determines how "easily" the temperature of a material changes is called **specific heat capacity (c)**. Each material has its own specific heat capacity. The higher the specific heat capacity of a material, the slower its temperature can change as heat is supplied. The law that describes the relationship between the change in temperature of a material and its specific heat capacity is called the **Equation of Thermodynamics** (**Q = m*c/ΔT**).

Q = heat energy
m = mass
c = specific heat capacity
ΔT = change in temperature

In the table below, you can see different materials and their specific heat capacities.

Specific heat capacity		
Material	$\frac{J}{g.K}$	$\frac{cal}{g.K}$
Aluminium	0,897	0,215
Silver	0,233	0,056
Tungsten	0,134	0,032
Granite	0,790	0,190
Glass	0,837	0,200
Oil	1,970	0,473
Wood	1,800	0,410
Water	4,186	1
Iron	0,449	0,107
Copper	0,385	0,092
Gold	0,129	0,030

The two chefs also argue about the cooking pot that will help them prepare their food in less time. Which of the following do you believe they have to choose?

- ○ An iron cooking pot
- ○ A copper cooking pot
- ○ An aluminum cooking pot
- ○ Any of the above. It does not make a difference.

Please explain your reasoning: ____

____

____

____

____

7.7 Earthworms' sense of light (biology, suitable for grades 5–6)

Factual information

Earthworms are often mistakenly considered to belong to a single species. Worldwide, however, there are about 670 different species of earthworms in the family *Lumbricidae*. For example, in Germany alone there are 46 different earthworm species. Earthworms belong to the phylum of annelid worms (*Annelida*), representatives of which are characterized by a segmented body with a skin of muscle tube. Unlike some other ringworms, earthworms have no eyes. Nevertheless, they can distinguish between light and dark. Earthworms have a sense of light. The skin muscle tube of the individual segments houses simple light-sensitive cells which, when illuminated, emit impulses to the nervous system. In this way, earthworms can perceive which segments are in the light and which are in the dark and coordinate the direction in which they want to move. This coordination is important for earthworms because strong sunlight damages them and staying in brightness makes them easily visible to predators. Earthworms therefore move away from light (this is call "negative phototaxis").

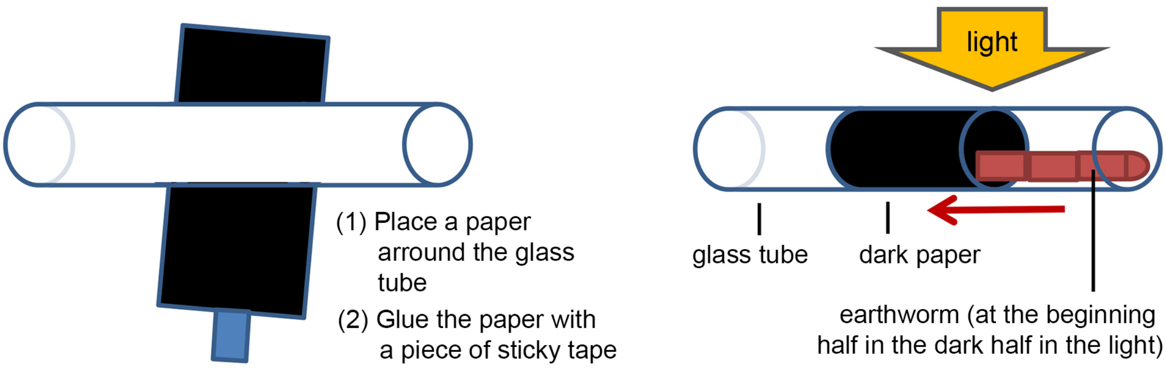


Fig. 7.7.1: Possible experiment to investigate earthworms' sense of light

Determination of the objective (domain of the lesson):

The lesson presented here is oriented at the epistemic domain. The focus of the lessons is on the training (practice) of competencies to reflect the planning and performing of the experiment.

The four decision stages of the Differentiation Tool:

1. Selection of setting

In this example, the teacher divides the learners into homogeneous groups so that the learners are given tasks of appropriate complexity for all members of the group. The general learning objectives are identical for all groups. However, there are differences in the training (further development) of competencies (see the lesson plan below).

2. Selection of the relative openness of the sub-phases

Figures 7.7.2 and 7.7.3 show the degrees of IBL openness considered for the groups (as with all examples in Chapter 7, two fictitious groups are shown as illustrations). As in the other examples, the different colors represent the different groups.

		0 closed	***1 moderately opened***	***2 opened***	***3 open***
	Orientation	Learners engage in a provided problem (phenomenon)	Learners select a problem (phenomenon) from a pool	Learners identify a problem (phenomenon) with support (verbal or medial)	Learners contribute problems (phenomena) to the lesson
Conceptualization	**Questioning**	Learners engage in a provided question	Learners select from a choice of questions	Learners develop a question with support (verbal or medial)	Learners develop their own question
Conceptualization	**Hypothesis Generation**	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop a hypothesis with support (verbal or medial)	Learners develop their own hypothesis
Investigation	**Planning and Conducting Investigation**	Learners work with provided instructions ("cook book")	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop their own design
Investigation	**Data Interpretation**	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
	Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop a conclusion with support (verbal or medial)	Learners develop their own conclusion

group 1
group 2

Teacher-directedness — **Student-directedness**

Fig. 7.7.2: Possible openness for the two groups

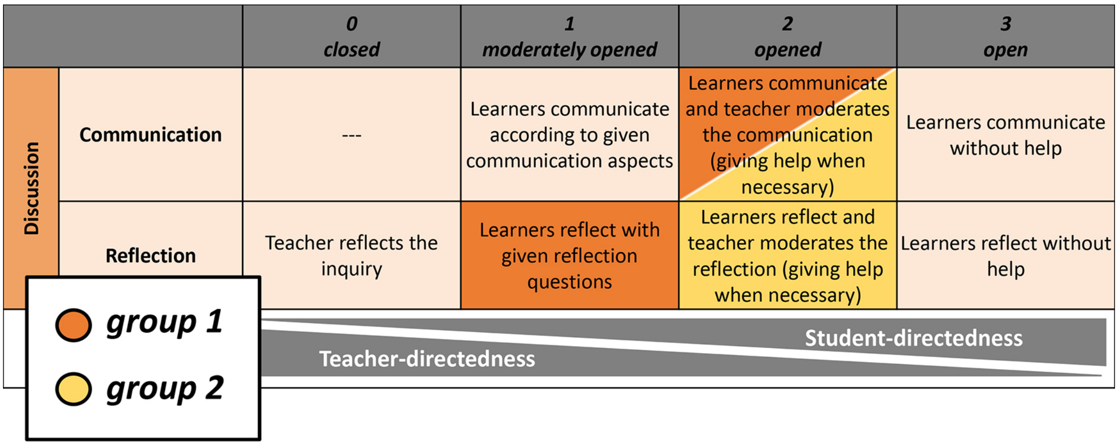


Fig. 7.7.3: Possible openness for the two groups

The groups are led to the problem via a guided class discussion (sub-phase *Orientation* is *opened*). For the sub-phase *Questioning, moderately opened* was selected for both groups as the degree of openness. Learners select a question from a pool (see the lesson plan below). The *Hypothesis Generation* sub-phase is planned to be *opened* to both groups. In a classroom discussion, hypotheses are formulated together. The sub-phase *Planning and Conducting Investigation* is offered in *moderately opened* form for group 1 and *opened* for group 2. Group 1 receives all the necessary materials and must use them to design an experiment setup. Group 2 only gets a glass tube and must think about all other materials. The *Data Interpretation* is designed to be *open* for both groups. The *Conclusion* is *opened* for both groups. As help, verbal prompts are offered in a class discussion with the entire class (possible prompts: "Is the hypothesis proven/refuted? How can this be recognized? Has the research question been answered?"). The *Communication* sub-phase is *open*ed for everyone. The teacher gives verbal help in the conversation if necessary. The *Reflection* is *moderately opened* for group 1 and *opened* for group 2. Group 1 receives reflection questions and Group 2 receives assistance when needed.

3. Selection of sub-phases to be scaffolded to the next level of openness

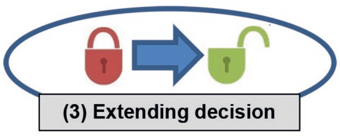


Figure 7.7.4 shows the sub-phase which is extended in its openness for both groups in the example.

The learners in the *moderately opened* sub-phase *Reflection* (group 1) are supported in reaching the next degree of openness (*opened*), and the students in the *opened* degree (group 2) are supported to come to the *open* degree. The procedure is explained in the lesson plan below. Not all reflections on the experimentation process can take place in group work due to time constraints. The reflection on the question is carried out in the classroom discussion and is therefore *moderately opened* or *opened* for all groups, depending on the amount of help the students need.

The reflection on the planned experiment and its implementation is realized in group work (in different degrees of openness).

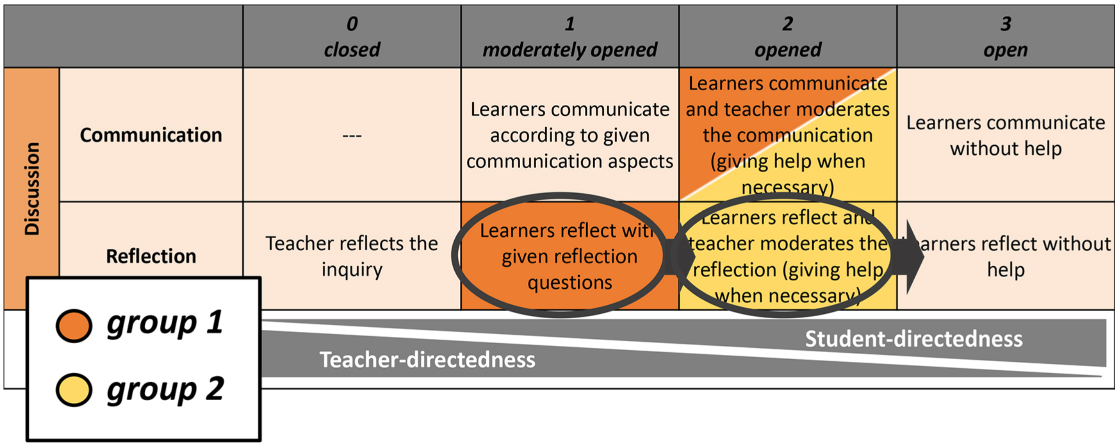


Fig. 7.7.4: Transition to the next level of openness

4. Selection of methods for scaffolding

For the sub-phase *Reflection*, a combination of prompts (questions) and help cards (see Appendix 7.7.III) was selected as the method of scaffolding for group 1 and help cards with prompts (see Appendix 7.7.II) for group 2.

Lesson plan

<table>
<tr><td>Grade: 5–6</td><td>Subject domain: Biology</td><td colspan="2">Topic: Earthworms’ sense of light</td><td>Duration: 60 min</td></tr>
<tr><td colspan="5">Prior knowledge:
Learners know:
what a scientific question and a hypothesis are;
that they need a test and a control trial for experimentation;
that a report and an experiment consist of different “sections” (question, hypothesis…) and they also know what is expected of them in these sections.</td></tr>
<tr><td colspan="5">Driving question: Learners are asked to find out if an earthworm can detect light and dark.</td></tr>
<tr><td>Learning objectives: must be feasible to put into operation and measurable against the learning products</td><td>Teaching/learning material: reference material, physical or virtual materials and resources</td><td>Learning activity: a description of what learners do, including the instructional support they receive</td><td>Learning product: needs to reflect knowledge or skills included in the learning objectives and allow a flow of learning activities</td><td>Assessment (formative, peer, or summative): focused on learning products</td></tr>
<tr><td rowspan="2">Learners plan and carry out an experiment and reflect their proceeding.</td><td>Figure (Appendix 7.7.I)</td><td>Teacher shows two images (Appendix 7.7.I) and lets the learners describe the differences between the images (classroom discussion). The teacher verbally gives prompts.</td><td></td><td></td></tr>
<tr><td>Pool of questions noted on blackboard</td><td>In their groups, the learners select a question that is suitable for an experiment from a pool of questions.
Possible questions to choose from: “1. Do earthworms have a closing mouth? 2. Can earthworms detect light and dark? 3. Why do earthworms live in the soil?” (Only question 2 is suitable.)
In a classroom discussion, the groups’ selected questions are checked for suitability and the necessity and relevance of a research question are discussed.</td><td>Research question</td><td>Impressions from the classroom discussion; if necessary, verbal help is given in the form of prompts.</td></tr>
</table>

		In a classroom discussion, hypotheses are formulated together.	Hypothesis	Impressions from the classroom discussion; if necessary, verbal help is given in the form of prompts.
	Help cards (Appendix 7.7.II) Prompts + help cards (Appendix 7.7.III) Glass tubes, black paper, adhesive tape, earthworms	In groups, the learners plan experiments, carry them out and reflect on the structure and execution of their experiment. Group 1 (*moderately opened*) receives all the necessary materials (glass tube, paper strips of black paper, adhesive tape, earthworms). Group 2 (*opened*) only receives a glass tube and must consider all the other materials. After the first attempts, the teacher gives the groups the tip that it is helpful to place the earthworm half in the dark and half in the light. After the execution, the groups must reflect on their experiments. Transition *Reflection* from *opened* to *open*: Group 2 can use help cards with prompts (see Appendix 7.7.II). Transition *Reflection* from *moderately opened* to *opened:* Group 1 receives prompts and help cards (see Appendix 7.7.III).	Planned experiment	Observations in the classroom; prompts if necessary. Learners' planning sketches (experimentation protocols) can be used for diagnostics.
		The learners record their observations in a report.	Data presentation	
		In a classroom discussion, the experiments and reflections of the groups are presented. Together, conclusions are drawn from the results.	Conclusion	Impressions from the classroom discussion; if necessary, verbal help is given in the form of prompts.

Appendix 7.7.I – Images for sub-phase *Orientation*

Appendix 7.7.II – Help cards for group 2

Task: You need to think about whether:

1. your experiment was assembled well.
2. your experiment was done correctly.

If you need help, you can use the help cards.

Help 1: Has a comparison (test and control) been considered?

Help 2: Why does it make sense to put the earthworm half in light and half in dark?

Help 3: Is it possible to make an evident statement with only one individual earthworm and a one-time execution of the experiment?

Annex 7.7.III – Prompts and help cards for group 1

Task: You now must think about whether you thought of everything when you carried out your experiment.

Use the prompts 1-3 and, if necessary, the corresponding help cards.

Prompts	Help cards
(1) Has a comparison (test and control) been considered?	Help: A comparison can be made by observing what happened at the beginning (control) and after a few minutes (test) or by building a test and a control trial. Did you have a comparison (test and control)?
(2) Why does it make sense to put the earthworm half in light and half in dark?	Help: Think about two things: (a) What could happen if the earthworm is too far from the dark and does not recognize the dark? (b) What could happen if the earthworm is already too far in the dark?
(3) Is it possible to make an evident statement with only one individual earthworm and a one-time execution of the experiment?	Help 1: Think about two things: (a) Should the experiment be carried out gradually with several earthworms? Reason! (b) Should the experiment be carried out several times with each earthworm? Reason!
	Help 2: (a) Does every individual earthworm react the same way? (b) Does an earthworm always react the same way?

8 Safety regulations in a laboratory and for experimental work

When experiments – with or without chemicals – are carried out at school, safety measures and precautions should be taken and laboratory rules must be introduced and followed.

The teacher must carry out a risk assessment before experimenting at school. This assessment comprises the collection of information about hazards, precautions and protective measures concerning the respective experiment. Where can one find the necessary information?

Table 8.1: Basic information about safety instructions for natural science subjects at school (August 2021)

Country	Information
Austria	Collection of documents concerning safety at school (*Allgemeine Unfallversicherung*): https://www.auva.at/cdscontent/?portal=auvaportal&contentid=10007.671658 https://www.bmbwf.gv.at/Themen/schule/schulrecht/rs/1997-2017/2016_22.html
Germany	RiSU 2019: Summary of regulations concerning safety at school, regularly updated: https://www.kmk.org/fileadmin/veroeffentlichungen_beschluesse/1994/1994_09_09-Sicherheit-im-Unterricht.pdf https://www.gesetze-im-internet.de/biostoffv_2013/BJNR251410013.html
Finland	Guideline book for safety in science teaching published by the Finnish National Agency for Education: https://www.oph.fi/fi/tilastot-ja-julkaisut/julkaisut/luonnontieteiden-opetustilat-tyoturvallisuus-ja-valineet or a direct link: https://www.oph.fi/sites/default/files/documents/137890_luonnontieteiden_opetustilat_tyoturvallisuus_ja_valineet_2.up__0.pdf
Cyprus	The safety instructions for the use of a school laboratory are provided only on the national chemistry education website: http://chem.schools.ac.cy/index.php/el/ergastirio/asfaleia-ergastirio. Among the files on this website are general safety instructions for the use of a laboratory for science education, which concern the subjects of physics, chemistry, and biology, for example: - Safety and Health Guide to Chemistry Laboratories: http://archeia.moec.gov.cy/sm/646/tee_chemistry_labguide_2019.pdf - Security Measures and Rules: http://archeia.moec.gov.cy/sm/646/metra_kanones.pdf - Safety Rules: http://archeia.moec.gov.cy/sm/646/kanones.pdf - Safety Instructions: http://archeia.moec.gov.cy/sm/646/odigies_asfaleias.pdf - Manual of Chemicals: http://archeia.moec.gov.cy/sm/646/encheiridio_chimikon_ousion.pdf - List of Incompatible Chemicals: http://archeia.moec.gov.cy/sm/646/katalogos_asymvaton_ousion.pdf

Safety regulations are continuously being updated, so the reader is advised to check the current standards. In Table 8.1 we provide some references as of 2021 relevant for schools in the countries of origin of the teachers participating in our interviews; in these countries, too, one must use up-to-date versions of the safety regulations. In some countries there are basic rules prepared specifically for teachers (e.g., RiSU in Germany, edited by the ministers of education and valid for all schools in Germany). So, the complex matter of safety becomes manageable, and no teacher should stop experimenting because of uncertainty due to unclear requirements.

Since the teacher is responsible for their class, safety rules must be discussed together at the beginning of the school year and before experimenting.
If the design/infrastructure of the classroom or other safety conditions are not appropriate for the planned experiment, the experiment must not be undertaken.

There are three levels of consideration necessary when checking safety:
(1) General safety measures in the school
(2) Equipment of the classroom or laboratory including lab rules for the learners
(3) Specific aspects depending on the chosen experiment, such as chemicals, heat and fire, electrical energy, and biohazards like micro-organisms, living animals.

These three levels are examined in more detail below. A short summary example of lab rules for learners is given at the end of this chapter.

Disclaimer: We recommend paying attention to the safety rules and safety measures given here. Additionally, the reader is obliged to find out the current required safety measures in their own country and school.

(1) General safety measures

- Emergency escape routes and fire extinguisher: the learners are informed about the exit routes. All exit routes must be kept clear during experimenting (no school bags lying around, etc.). Also, the position of the fire extinguisher is known, and the fire extinguisher is easily accessible.
- Emergency equipment: when emergency stop switch, eyes showers and emergency showers are at hand, their function must be checked regularly.
- First-aid equipment: a first aid kit should be part of the basic equipment in every laboratory room and classroom used for experiments. Check this first aid kit regularly and refill it when anything is missing!

(2) Equipment of the classroom or laboratory

- Work surfaces: the surface of the tables must be chemical-proof and heat-resistant, depending on the experiments chosen. Otherwise, one can use a fireproof underlay, such as refractory tiles or metal plates.
- Protective gear/personal protective equipment: the teacher makes sure that learners wear suitable clothing or appropriate protective clothing such as safety glasses, eye protection, gloves (disposable), lab coats (when necessary).
- Storage: for some experiments, materials must be kept refrigerated or cooled (certain chemicals or dead animal matter used for dissection like fish or pig eyes). Label such materials and do not store them together with food!
- Some experiments must only be undertaken using a fume cupboard!

(3) Special aspects depending on the experiments carried out

a) Risk assessment

Teachers are obliged to carry out a risk assessment before experimentation in the classroom. Depending on the planned experiment, the following aspects can be part of a risk assessment:

- Is it allowed to carry out the experiment at the grade level in question? This sometimes depends on hazardous substances that must not be used by younger pupils.
- Some experiments may only be carried out by the teacher.
- What dangers or hazards can occur when using a given substance, animal, micro-organism, equipment, or electronic device?
- When using hazardous substances, one must consider possible substitutes.
- Of course, the teacher must find out which precautions have to be taken, which emergency measures have to be prepared and how to ensure and organize proper waste disposal.

Forms for risk assessments are generally provided by the school administration.

b) Chemicals, hazardous substances, and materials

Table 8.2: Globally harmonized system of classification and labelling of chemicals

Symbol	meaning
	***GHS 01 Explosive*** • Explosives • Self-Reactives • Organic Peroxides

	***GHS 02 Flammable*** • Flammables • Pyrophorics • Self-Heating • Emits Flammable Gas • Self-Reactives • Organic Peroxides
	***GHS 03 Oxidizing*** • Oxidizers
	***GHS 04 Compressed Gas*** • Gases Under Pressure
	***GHS 05 Corrosive*** • Skin Corrosion/ Burns • Eye Damage • Corrosive to Metals
	***GHS 06 Toxic*** • Acute Toxicity (fatal or toxic)
	***GHS 07 Harmful*** • Irritant (skin and eye) • Skin Sensitizer • Acute Toxicity (harmful) • Narcotic Effects • Respiratory Tract Irritant • Hazardous to Ozone Layer (Non-Mandatory)
	***GHS 08 Health hazard*** • Carcinogen • Mutagenicity • Reproductive Toxicity • Respiratory Sensitizer • Target Organ Toxicity • Aspiration Toxicity
	***GHS 09 Environmental hazard*** • Aquatic Toxicity
https://www.osha.gov/sites/default/files/publications/OSHA3491QuickCardPictogram.pdf	

- Teachers must find out usage requirements and prohibition of use of chemicals. They must carry out substitute testing and they must check any intermediately occurring substances as well.
- Chemicals: since 2015, all chemicals are marked with danger symbols– so-called "pictograms". The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) pictograms are valid worldwide. Teachers must check whether all chemicals are labelled properly. The learners should become familiar with the meaning of the GHS pictograms before handling chemicals. So, they know about the hazards of the substances and they can take the necessary precautions against injury and damage. Table 8.2 shows the current GHS pictograms.
- Storage of chemicals: teachers care for proper storage containers (no containers used for food!), correct labelling and necessary storage conditions (refrigerator, safety storage cabinets if necessary).

c) Fire and heat

- Bunsen or Teclu burners, gas cartridge burners, and candles are used with naked flames. No inflammable substances should be heated or used at the same time in the room. Pay attention to dangers posed by long hair or bulky clothing!
- For heating liquids like water, heating plates or microwaves are used. Take care around hot surfaces, hot vessels, and boiling delay!

d) Work equipment

- To avoid injuries, handling potentially dangerous equipment such as glassware or sharp tools like scalpels, needles, scissors, and knives, must be trained for.
- Even when using everyday items, learners must practice correct handling and be informed about dangers and precautions.

e) Biological agents and living organisms

- One must obey basic safety rules, mostly drawn from everyday life, concerning safe handling and hygiene to avoid infections and contaminations. This holds true for working with bacteria, moulds, parasites, and living organisms that may carry pathogens.
- Special requirements for working with microorganisms: table surfaces must be solvent-safe (use of alcohol for cleaning); a wash basin with a soap dispenser, paper towel dispenser, and disinfectant are also necessary. There must be a possibility to sterilise contaminated material (e.g., autoclave, pressure cooker).

- In general, these regulations and requirements also hold true for experiments with living organisms or during dissection of animals (trout or other fish) or organs (lung, liver, pig eye, pig heart…).
- Remarks on living animals at school: read up on legal issues (protection of animals and the environment), ethical and emotional aspects (disgust, phobia), and how to properly keep animals.
- Check precisely which living animals you are allowed to bring to school in your country! All animals should be healthy and unharmed. Poisonous or dangerous animals and animals which could provoke allergic reactions are not allowed in the classroom.
- Rules of hygiene must be obeyed when handling or keeping animals to avoid zoonoses, meaning pathogens which are transferred from animals to humans. Hygiene measures comprise washing hands thoroughly, keeping animals in adequate/species-appropriate conditions, and checking the health of the animals regularly.
- Do not collect animals or other material in nature protection areas!
- Animal testing that causes injuries or unnecessary stress is strictly forbidden. The rules for vertebrates (dogs, mice, etc.) are stricter than those for invertebrates (snails, earthworms, etc.). Teachers should make sure that no animal is hurt during experiments at school!
- When keeping animals at school in the classroom for a longer period of time, one must consider the following organisational issues: the animals must be kept in a species-appropriate way and looked after according to animal protection law. Technical facilities (light, heating) must be installed and maintained. Finally, it must be clear what happens to the animals after their time at school!

f) Electric energy and electrical devices

Electrical equipment is used not only in physics but also in many experiments in biology and chemistry lessons (heating plates, microscopes, lamps, refrigerators, etc.). The handling of these devices does not differ from proper handling in everyday use. Experiments with electricity/electrical current must only be performed in accordance with the respective national regulations.

Instructions for use of electric energy at school and in everyday life (according to RiSU 2019, see Table 8.1)

- Check all cables, plugs and devices/equipment for damage and malfunction before using them in the classroom!
- Switch off voltage immediately when disturbances or malfunctions occur!
- Report malfunctions and damage to the relevant authority. The respective equipment must be taken out of use at once.
- Repairs of electrical devices, cables, sockets, and switches must be carried out by an electrician. Only simple steps like changing a bulb may be done by the teacher.
- Cables: watch out for kinks and tripping hazards!
- Protect electrical equipment against water and humidity; do not use wet electrical devices!
- Safety devices must not be manipulated nor turned off!
- Experiments with electricity supply directly from the mains supply may only be carried out if the proper safety devices are present and fully functional (e.g., emergency switch, RCCB: Residual Current Circuit Breaker).
- Use only devices with valid labelling for the respective country. Ensure that the device's latest safety check is up-to-date!
- Use electrical devices only for the intended purpose and observe the operating instructions!
- Electrical devices in a school must be checked regularly by an electrician. The test intervals are different for portable and permanently installed devices. Find out about the current regulations in your country!
- Learners are not allowed to perform experiments using hazardous voltage. Therefore, the following safety regulations have to be respected:

  Only electrical devices with extra-low voltage may be used for school experiments (EN 61558-2-6; e.g., safety transformers, accumulators). In safety transformers (see Figure 8.1 for the symbol), the primary and secondary coils are fully separated.

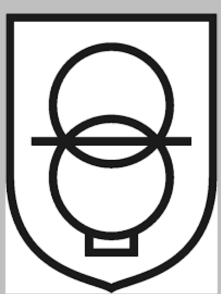


Fig. 8.1: Safety insulating transformer label, IEC5222

Some hints from practical experiences at school:

- Point out that banana plugs must not be connected with power outlets!
- Don’t touch circuits after providing the operating voltage. After finishing the experiment, switch off the voltage and disconnect the cable connections.
- Caution with capacitors of more than 60V voltage: provide protection against contact and discharge capacitors before disassembling the experimental set-up.
- Accumulators and batteries: never try to charge a primary battery, there is a risk of explosion! To charge accumulators, use only the charger provided or recommended by the manufacturer.
- Electromagnetic fields and radiation: devices which are normally used at school do not reach the limit values of exposure when they are used appropriately. Follow the manufacturer’s instructions, especially when you are working with invisible radiation like microwaves.
- Attention: protect people with implants like cochlea implants and pacemakers from electromagnetic fields. They must keep sufficient distance or leave the room.

g) Mechanics and mechanical stability

- For all experimental set-ups, it is important to pay attention to mechanical stability, especially when stands are used.
- During certain experiments, heavy masses are moved; they can become hazardous when colliding with people’s bodies. Be careful when working with loaded springs and wires, high pressure, tackle/pulley, or rotation experiments.

h) Thermodynamics

When using pressure vessels for heating of water, one must check the safety valves before starting the experiment. Do not exceed the maximum pressure limit!

i) Optics and optical radiation

Most radiation sources used in school are also used in everyday life and at home. Safe handling of these natural and artificial light and radiation sources features among the aims of instruction in the natural sciences.
Examples for such radiation sources are household standard illuminations like filament or fluorescent lamps, lasers and laser pointers, ultraviolet (UV) and infrared lamps, LEDs, open flames, sunlight and focused sunlight, spectral lamps, and flashguns.
One must respect exposition limit values with most of these radiation sources. These limits depend on time, distance, and the type of radiation. At school especially, current, short-term values are important (glare, damage to eyes); conditions making long-term limits relevant should not occur.

Normally, one can use the following radiation sources without special protective measures: bulbs used in the household, bill validators, black-light lamps, small light-emitting diodes (LEDs), open flames, and flashguns.

Protective measures are needed for the following radiation sources; they may only be used when the teacher is present and the learners have received proper instruction.

- Lasers and laser pointers: avoid glare; take care that nobody can look directly into the beam path.
- Ultraviolet lamps: avoid exposing skin to UV radiation.
- Spectral lamps: observe the operating instructions; use protection against scattered light, mark the workspace with an appropriate sign/label.
- High-power LEDs: never aim these LEDs at eyes because of the danger of glare and damage.
- Focused sunlight: there exists a danger of burns and fire hazards; do not look into the beam path or directly towards the sun!
- Infrared lamps: keep a distance of at least 50 cm. The distance to inflammable items must be more than 1 meter. Do not operate infrared lamps without surveillance!

Appropriate behavior in the laboratory: general rules for learners

- do not eat
- do not drink
- keep your working station clean and follow the hygiene rules: clean or disinfect when necessary
- do not run (avoid collisions, avoid spilling substances)
- keep your working area and aisles clear: no coats or bags on tables or in the way
- wear eye protection; when necessary, also use disposable gloves and/or a lab coat
- when working with naked flames (e.g., Bunsen burners, candles) tie back long hair and remove bulky clothing like coats and scarves
- wash your hands carefully after working with chemicals, animals, animal or plant material, or microbes
- report any damage or injury to the teacher

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