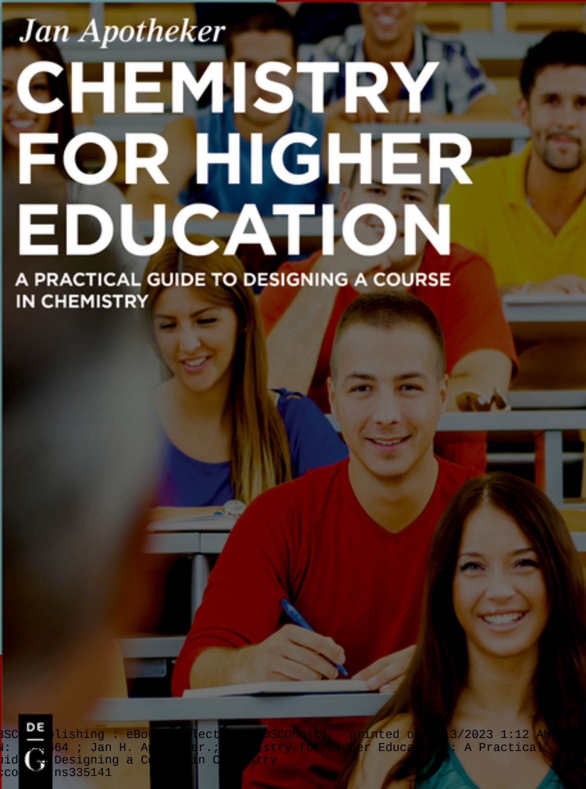
DE GRUYTER

GRADUATE



Jan Apotheker

CHEMISTRY FOR HIGHER EDUCATION

A PRACTICAL GUIDE TO DESIGNING A COURSE IN CHEMISTRY

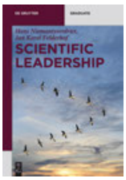
Jan Apotheker

Chemistry for Higher Education

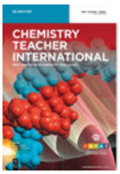
Also of Interest

Green Chemistry Education.
Recent Developments
Green Chemical Processing series, Vol. 4
Benvenuto, Kolopajlo (Eds.), 2018
ISBN 978-3-11-056578-2, e-ISBN 978-3-11-056649-9

Risk Management and Education.
Meyer, Reniers, Cozzani, 2018
ISBN 978-3-11-034456-1, e-ISBN 978-3-11-034457-8



Scientific Leadership.
Niemantsverdriet, Felderhof, 2017
ISBN 978-3-11-046888-5, e-ISBN 978-3-11-046889-2



Chemistry Teacher International.
Best Practices in Chemistry Education
Apotheker, Maciejowski (Editors-in-Chief)
e-ISSN 2569-3263

Jan Apotheker

Chemistry for Higher Education

A Practical Guide to Designing a Course in Chemistry

DE GRUYTER

Author
Jan Apotheker
Retired from University of Groningen
Department of Chemistry Education
Nijenborgh 9
9747 AG Groningen
The Netherlands

ISBN 978-3-11-056957-5
e-ISBN (PDF) 978-3-11-056958-2
e-ISBN (EPUB) 978-3-11-056983-4

Library of Congress Control Number: 2018952172

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at http://dnb.dnb.de.

Cover image: skynesher / Vetta / Getty Images
Typesetting: Integra Software Services Pvt. Ltd.
Printing and binding: CPI books GmbH, Leck

www.degruyter.com

To José and Annemarie

Preface: Chemistry and Chemistry Education

Both chemistry and the teaching of chemistry have changed over time. Chemistry as a separate science did not start until the late eighteenth century with the work of Proust and Lavoisier. In the nineteenth century, the art of separation of compounds and elements was one of the major accomplishemnts of chemistry. It is one of the reasons Chemistry is still called 'Scheikunde' (science of separation). With the start of organic synthesis, another more molecular part of chemistry evolved. In the late nineteenth century and early twentieth century, the atomic structure was discovered, which led to the discovery of a whole new range of elements. In the second half of the twentieth century, biochemistry started evolving. By now, we have a major insight into the molecular background of all aspects of life.

The teaching of chemistry as a separate subject in secondary schools did not start until the second half of the 19th century, about the same time as chemical research groups began to start up in most countries.

These developments have changed the nature of chemistry, but have also changed the role chemistry plays in society. The attitude towards chemistry has changed over the years. In the late nineteenth century, chemists were playing with life, building and making molecules that also occurred in living things. For an interesting view of the discussion at the time, see Dorothy Sayers novel *The documents in the case* (Sayers, 1995).

It contains a very nice and accurate description of the vital experiment in the book. In 2019, we will be celebrating the International Year of the Periodic Table. Mendeleev proposed the periodic table in 1869 (Fechete, 2016). The periodic table is by far the most characteristic element of chemistry for the general public. By now it contains 118 elements and is considered full. IUPAC, the International Union for Pure and Applied Chemistry, which celebrates its centennial in 2019, is the body that plays a major role in deciding about the names of the elements.

Attitude towards chemistry

In the 1960s and 1970s, pollution became synonym of chemical plants and chemistry. The attitude towards chemistry changed drastically. In later years, this led to a drastic decrease in the number of students choosing science as a major. In a recent report, Kennedy et al. (Kennedy, Lyons, & Quinn, 2014) showed a marked decrease in the number of students enrolling in chemistry and physics in Australia. In Europe, this trend started earlier (Rocard et al., 2007) and led to a discussion about the need to change the nature of chemistry education (Osborne & Dillon, 2008). This discussion continues till today. In some countries, this decrease is less marked, in others it is more.

In Figure P.1, an overview is given based on the ROSE (Relevance Of Science Education) report (Sjøberg & Schreiner, 2010) about the way students from different countries appreciate chemistry education.

https://doi.org/10.1515/9783110569582-201

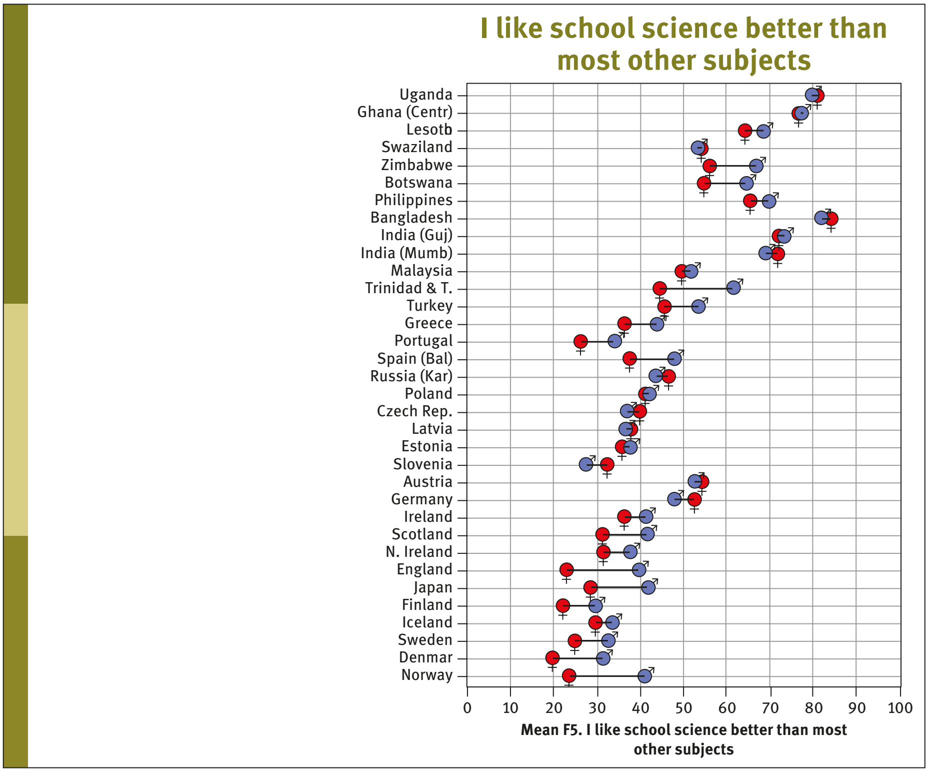


Figure P.1: Overview of attitude towards science (Sjøberg & Schreiner, 2010)

One of the things that is interesting in the ROSE-report, which examined quite a few things about interest in science, is the attitude towards the environment, which is depicted in Figure P.2.

But other results are not very encouraging for chemistry education.

Relevance for education

The Rose report and other reports from the EU (Rocard et al., 2007) (Osborne & Dillon, 2008) have given rise to new developments in science education. In these new developments, one of the most important issue has been to demonstrate in a clearer way the role science, and chemistry in particular, plays in society. Context-oriented chemistry education like CHIK (Nentwig, Demuth, Parchmann, Gräsel, & Ralle, 2007) in Germany or new chemistry in the Netherlands (Apotheker, 2004) was developed to demonstrate between chemistry and society more clearly. One of the ideas behind these experiments is that chemistry is the science that makes the connection between

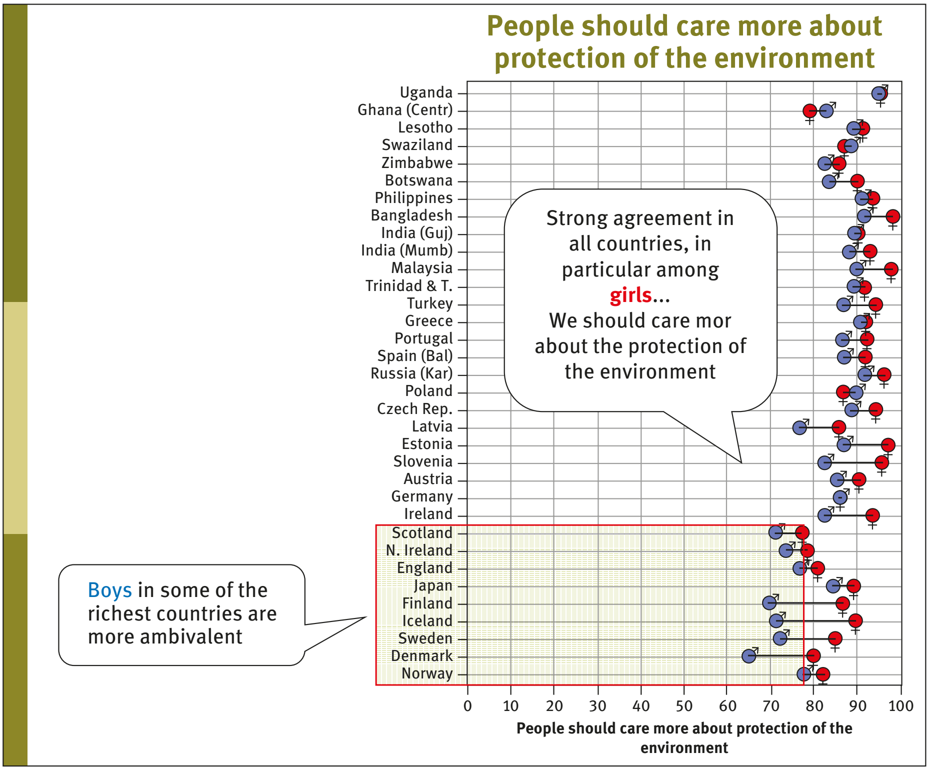


Figure P.2: Attitude towards the environment (Sjøberg & Schreiner, 2010)

macroscopical phenomena and properties at the molecular level. Chemistry in that sense is a molecular science.

This change in education, and specifically the change in focus of education, from teacher to student, has become more and more important in a number of countries. Together with this development, other developments have taken place in the relation between teacher and students. Students are expected to be more active in their own educational activities. They get more responsibilities. The role of a teacher has shifted from being the main source of information and being an authority to that of a coach who is responsible for the learning process of students. This change of focus is important for higher education as well.

Higher education

These developments also have an effect on higher education. The role and focus of teachers need to change into an attitude that is focused on the learning process of the

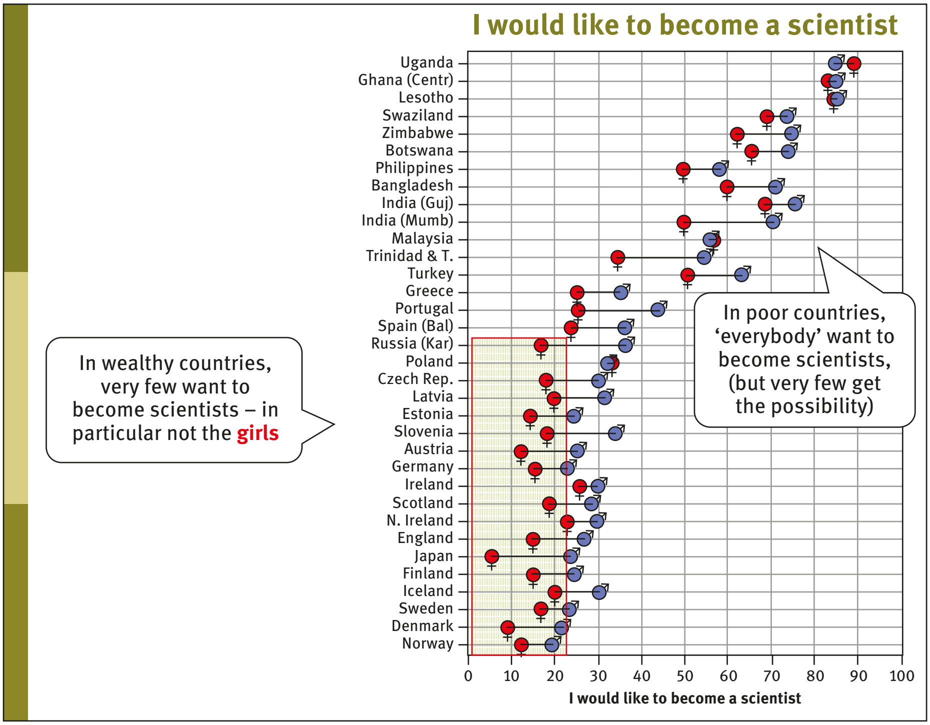


Figure P.3: Who wants to become a scientist (Sjøberg & Schreiner, 2010)

students. An important factor in the teaching is to keep students interested enough in chemistry, so they don't drop out after the first year. Their attitude towards chemistry is as important as the science they are learning. The appreciation of the beauty and elegance of chemical processes is something that needs to be passed on to students. When students are able to glimpse some of that feeling, they will keep their interest in chemistry, even if they continue into engineering, medicine, dentistry or some related subject.

It gives teachers and lecturers in higher education an extra responsibility, keeping up the population of (research) chemists.

This book

This book is meant to be used as a guide for the design of a course in higher education. In this book, several aspects of setting up a course will be discussed, including lectures assessment and other learning activities. Each chapter can also be read separately. An introduction will be given about some of the research about learning. This background will give a prospective teacher a better idea of how students learn science, and chemistry, in particular.

Contents

1 Pedagogy

1.1 Introduction

Learning is a process that is taking place continuously. From birth people learn to adapt to their environment and learn how to act in a suitable manner. Learning in school is a way of learning that has been researched since the late nineteenth century. Maria Montessori (1912) indicates that she was inspired by the work of a French scientist Itard, who studied the learning of the savage of Aveyron around 1810. She later developed the "Montessori" method for teaching young children. Somewhat later Petersen (Hooijmaaijers, 2000) developed in Jena another methodology for teaching, as well as Freinet (French Embassy NY French, Cultural Services, 1971) in France, and Parkhurst (van, 2014) in the United States. Montessori focuses on individual learning of children. Petersen has his focus more on social learning, in which students work together in groups and support each other's learning. Freinet and Parkhurst give the student a responsibility in their learning process, especially in the panning of the learning goals. Freinet does that for the whole classroom, Parkurst does that more individually. All of them have one thing in common in that they focus on the learning process of children. They give the student a central role in his learning process. Even though these methodologies were developed in the early twentieth century, they are still practised in schools today, even though a lot has happened since then.

After the Second World War, research in the effectiveness was initiated, by Bloom (Anderson & Krathwohl, 2001) for example. He formulated his taxonomy of learning in order to be able to measure the effectiveness of teaching. He discerned three major domains of development – the cognitive domain, the psycho-motoric domain and the affective domain. For each of these domains, he formulated levels, from beginner to expert. These definitions made it possible to measure the effectiveness of teaching, by checking the increase of aptitude in each of the domains. These domains have been expanded by Gardner (1993) into what he called multiple intelligences. These are slightly different from the domains defined by Bloom, because they indicate areas in which people can develop themselves. However, for teaching they have a similar importance. It is important to use the domains and the so-called intelligences as areas in which a student may gain expertise. The multiple intelligences identified by Gardner are related to the domains of Bloom in Table 1.1.

These domains and intelligences can serve as a background to the design of teaching activities. It should be clear that students differ in their aptitude to develop themselves within these intelligences and domains.

Even though the intelligent quotient, which is derived from a standardized test, is important in secondary education (Ziegler & Heller, 2000), it does not play a major role in higher education, because students will have a fairly high IQ if they have been able to get into higher education.

https://doi.org/10.1515/9783110569582-001

Table 1.1: Gardner's intelligences linked to Bloom's domains.

Intelligences	Short description	Bloom's domain
Visual-spatial:	Thinking in 3D, awareness of environment	Cognitive
Logical-mathematical:	Thinking conceptually, exploring patterns and relationships	Cognitive
Linguistic:	Using words effectively in different circumstances	Cognitive
Bodily kinesthetic:	Ability to use tools and body effectively	Psycho-motoric
Musical:	Sensitive to rhythm and sound	Psycho-motoric
Interpersonal:	Ability to work in groups, interact with others	Affective
Intrapersonal:	Understanding the own learning process	Affective
Naturalistic:	Aware of the natural environment, ability to recognize species easily	Affective

1.2 Piaget

After birth, everybody starts learning to interact with their environment. People learn what to expect in their families, their house, their neighbourhood and so on, a language for communication is developed, involving both aural language and body language. People experience phenomena and try to find the explanation for what they experience. According to Piaget (Figure 1.1) (Nurrenbern, 2001), four periods of

Figure 1.1: Jean Piaget in Ann Arbor.

intellectual development are taking place in an individual. These correspond more or less with age. Important is that the stages are hierarchal in the sense that you have to pass through the previous stage before getting to the next. On Internet (google and YouTube) several examples of these stages may be found.

The first of these stages is the sensorimotor stage, which occurs in the first 2 years of life. In this stage, the senses are developed, children learn that when they do something this may have an effect. They learn that an object is still there even if they don't see it.

In the pre-operational stage (between 2 and 7 years of age), children think that when lemonade is poured in a high glass it is more than the same amount poured in a wide glass. If you put coins in a row and enlarge the space between the coins (so five coins with one inch space between them compared to five coins with two inches between them), children think there are more coins. But they also learn to use words and pictures to represent objects, and start learning to read and write.

In the concrete operational stage (age 7–11 years of age), children leave this behind and are able to do calculations, follow algorithms and so on. In the last stage, the period of formal operations, children are able to use abstract reasoning, such as: "if this happens then that has occurred". They can derive a general principle.

Children are normally able to study the laws of physics, as this mainly requires the operational phase, even though phenomena are described in terms of formulas. Using these formulas to predict what will happen in a certain situation is much more difficult. Chemistry is a lot more difficult to grasp, as you have to imagine molecules and atoms. They cannot be seen. The rules that govern their properties are arbitrary and logical reasoning is needed to fully understand this. The formal operational stage (12 years to adulthood) is needed to be able think abstractly, and reason about hypothetical ideas and problems. They are now able to understand syllogisms, for example.

It is possible to train students to progress from the concrete operational to the formal operational stage by challenging them (Schwarz & Heimann, 2016). Asking them to predict the outcome of experiments, for example, leads them to think and extrapolate. An example is an experiment involving a can of regular coca cola and a can of diet coke. The diet coke can is cooled in the refrigerator beforehand. In the first experiment, the students are asked to predict whether or not the cans will float in water. The experiment is then performed, by bringing the cans in water and observing whether or not the cans float.

The students will note the regular coke sinks and the diet coke floats (Figure 1.2). They are then asked to formulate an explanation. In the second experiment, the cans are placed on their side on a slope. Students are asked to predict whether the cans will roll down at the same speed (remember the diet coke is colder and has a lower density). When the experiment is performed, they roll at the same speed. Now one of the cans is shaken vigorously. Students are asked again whether this will make a difference. When the experiment is performed, the shaken can moves

Figure 1.2: Difference between diet coke and regular coke.

a lot slower than the other (see https://youtu.be/fjxwYdUJRh0). Again students are asked to explain. The answer is that in the shaken can the resistance between the liquid and the can has increased, because of the higher pressure in the shaken can. This causes the liquid to start rotating as well. Part of the rotational energy is used to set the liquid in motion. This does not happen in the non-shaken can. Walter Lewin gives a brilliant show about the phenomenon on YouTube (https://youtu.be/cB8GNQuyMPc).

This type of unexpected results calls for hypothetical thinking in students. It helps them develop their thinking skills and makes the step to the formal operational stage easier. Because the result is unexpected, it also triggers their imagination.

1.3 Vygotsky

Vygotsky (Figure 1.3) was a Russian psychologist from the beginning of the twentieth century. He was by chance discovered in the 1970s by an American psychologist, who bought his book at a stall in a book market (Vygotsky, 1978). Vygotsky is considered the father of constructivism. This theory about learning indicates that each individual constructs his own knowledge, combining new knowledge with knowledge that he already

Figure 1.3: Lev Vygotsky.

has. When a child develops itself, it forms explanations and ideas about the world around it. In order to interact with the world, behavior and concepts are developed. These are needed to deal with societal issues like traffic for example. A child learns to estimate correctly whether or not it can cross the road safely. It derives ideas about science that way as well. These ideas are applied when a child is confronted with a new situation. It wants to understand and comprehend the things and phenomena it experiences.

Language plays an important role in internalizing knowledge. That is why discussion with and among students is so important. Some concepts are not easy to understand. The concept of molecules and atoms as building blocks of matter is an example. The consequences and logic around such a concept needs to be discussed by students and teachers in order to clarify any misunderstandings and misconceptions.

The idea that new knowledge is linked to existing knowledge is contrary to the belief of the mind as a "tabula rasa" as coined by John Locke (Duschinsky, 2012) – the mind as a blank piece of paper – on which new knowledge can be written. This idea has persisted for a long time.

A nice illustration of the way prior knowledge or preconceptions play an important role in the learning process is demonstrated by a children's book. It is written and drawn by Leo Lionni and titled *Fish is Fish* (Lionni, 1970) . In this book, the story is told of a minnow and a tadpole that grow up together in a pond. After a while the tadpole grows legs and becomes a frog. He decides to go onto the land and visit the dry world. After a while he returns and has wonderful stories about things he has seen such as birds, cows, walking people and so on. He is fairly accurate in his descriptions. Lionni draws the images the fish makes of what he has been told (see for example https://youtu.be/N7jAo5aWhv0).

In his drawings, certain aspects of what the minnow has heard are connected to the basic image of a fish. He draws a fish with horns, black and white spots, a pink udder and so on.

This is exactly what happens when students learn new things they are connected to the knowledge they already have. These preconceptions are extremely important as they influence what students learn. When molecules and atoms are introduced there, first idea will most likely be to think of these as something like marbles.

In the BBC-documentary Simple Minds (https://youtu.be/0uP1KH6rAJU), the role of misconceptions is explained elegantly. In the documentary, graduates from MIT are interviewed, giving them a piece of wood. They are then asked where the mass from the wood came from. They have no clear idea. They think the mass comes from the soil. When informed the main mass is coming from carbon dioxide they are surprised, as that is a gas. Any idea of photosynthesis is missing. Some of these misconceptions are very strongly rooted in individuals. In the documentary, the role of teaching is discussed. It becomes clear that it is very difficult to get rid of some misconceptions.

Another important aspect of Vygotsky's theory is his definition of "the zone of proximal development". This is more or less defined as the zone in which new knowledge can be internalized/ learned meaningfully. If you try to teach someone a subject, which is too far away from this zone, learning will not occur. An example is learning about Rutherford's atomic model. If you have no idea what a proton, neutron or an electron is, it is not possible to understand the idea of Rutherford's model.

When teaching you help a child raise the level of proximal development, and the boundaries shift upward. What is important is that a child needs help to grow within his zone of proximal development. That can be done by a teacher, but a fellow student may help as well. If you cannot solve a problem by yourself, perhaps together it is possible to solve a problem. Letting students work together on problems helps them to use grow in knowledge and skills.

The zone of proximal development is not static. It keeps on shifting, as students gain more expertise. Determining what the upper boundary of the zone of proximal development is is an important facet of teaching.

1.4 Other pedagogical theories

Of course, there are more educational theories that are used in pedagogy like cognitive theory and behaviourism. Eric Scerri (2003) discusses the relationship between several learning theories and education. One of his conclusions is that the definitions and concepts of several –isms is different in pedagogy, then in philosophy and psychology. It is beyond the scope of this book to go into these deeper.

1.5 How people learn

In 2000, a book edited by Bransford and Cocking (2000) described in detail the research about the way students learn. From knowledge about the learning process, ideas can be derived how students should be taught.

Three key findings that are linked to the theories described above are cited here:

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.
2. To develop competence in an area of inquiry, students must:
   (a) have a deep foundation of factual knowledge,
   (b) understand facts and ideas in the context of a conceptual framework, and
   (c) organize knowledge in ways that facilitate retrieval and application.
3. A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

These findings of course have an enormous impact on the way work in the classroom or lecture hall should be organized. One of the key ideas to be derived from the book is the central position the learning process in the student takes in the teaching and learning process. It is a major shift in the attitude and focus of teachers. Not only the science content is leading in the teaching process, but guiding and coaching the students in their learning becomes the central theme. Teaching as a one-way process from teacher to student is changing into an active cooperation between students and teacher, and of a cooperation between students.

Since the book appeared, a lot of publications about activities in which these key findings play a central role have been reported. A phenomenon like the flipped classroom (Reid, 2016), for example, which is a hot topic in recent years is directly related to the first finding reported.

1.6 Cognitive theory in educational psychology

Learning takes place in your brain. On the molecular level, the working of memory is still not understood. It is clear that learning is an individual process. So it is difficult to find information about learning. Still on the macroscopical level a number of things may be observed. In educational psychology many of these processed are being researched. Both Piaget and Vygotsky are examples of people working in that research.

Cognitive theory in educational psychology looks at the way knowledge is developed in the individual mind (Swiderski, 2011).

The first step in learning is the processing of information. Before you can learn anything, you first have to obtain and process information. In general, information is gathered through your senses. You hear or read words, or you see phenomena. These will be taken up by your brain and then processed so that you may remember them. In your brain information is stored in a particular and individual way. When learning you may retrieve knowledge you already have to link that to the new information.

The design of the teaching and learning process can be helped by some knowledge about the way information is processed by people. Several people have done extensive research in this field. One of the models that is useful is the learning model of Baddeley (Johnstone, 1997).

In Figure 1.4, this model is described in a schematic way. The background of the model is as follows. Information is introduced through senses. Apart from ears and eyes, touch, nose and position may also play a role. This information is then passed through a filter, and subsequently introduced into the working memory. This filter is monitored by the long-term memory in a number of ways.

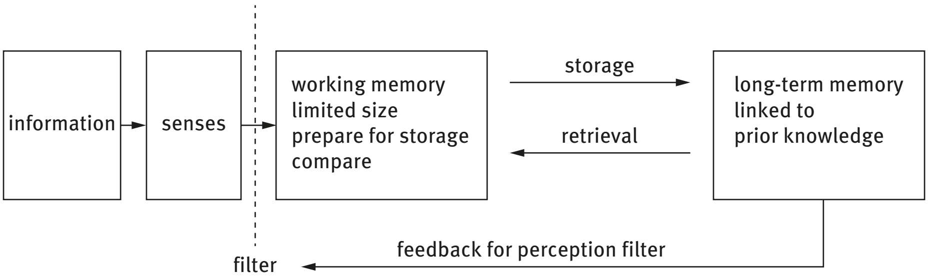


Figure 1.4: The learning model of Baddeley, as described by Johnstone (1997).

From the working memory, it may be passed on to the long-term memory, where it will be connected to knowledge that is already there. The filter is related to what you already know and expect to see. You have a certain bias when you observe. On Internet there exists a tape about a basketball game in which a monkey moves between the players (https://youtu.be/nJyWIghprxI, for example). You don't see that until your attention is specifically directed to it. In science, this happens as well. Scientists have a certain bias when observing things. If you ask a chemist to examine a coin, he will note it is made up of brass and some sort of nickel alloy. A physicist will comment on the shape, density and such like properties. A sociologist may look at the value and the use of a coin. The filter you use to observe is influenced by your permanent memory.

The size of the working memory varies between persons from four to six places. The connection with previous knowledge and the perception filter has been described by de Groot (1946) in his dissertation. He let people look at a chessboard containing chess pieces for 30 seconds or so. He then removed the chess board and asked them to reproduce the board. Nobody was able to replace more than six pieces correctly. When he asked master chess players to do the same, they were able to reproduce almost the whole board. They remembered the board in a different way. For them it was, for example, Nimzo-Indian opening move 10. This only takes one place in the working memory. When the logic was taken out the board, by using several queens and kings for example, these masters also reverted to a maximum of six places.

What is important to note is that this makes it easier to remember and retrieve facts. A simple mnemonic like: "Happy Henry Lives Beside Boron Cottage, Near Our Friend Nelly Nancy MgAllen. Silly Patrick Stays Close. Arthur Kisses Carrie" for the first 20 elements in the periodic table is easier to remember than 20 different names that have no meaning to you. And thus, have no link to earlier knowledge.

It also explains some of the difficulties in learning a new concept. If there is no relation with things learned before, a completely new knowledge base needs to be built up. Once this process has started building up, knowledge becomes easier. The number of places occupied in the working memory becomes smaller, and more information may be processed.

In chemistry, for example, the concept of the equilibrium quotient takes several places in the working memory. You need to know several things. You need to be aware of what concentrations are, in order to understand concentration you need to understand the concept of the mole as well as volume. In terms of reactions, you need to be aware that reactions can go both ways, depending on the conditions. Once the concept of equilibrium quotient is internalized, it only takes up one space in the working memory, making it possible to tackle more involved problems. This process has been called chunking of knowledge.

The relationship with learning immediately becomes clear. You cannot introduce too many new concepts at the same time. These concepts need to be internalized first. In an article Johnstone (1997) discusses the results of a data collection by the Scottish examination board about questions they had prepared about the mole. In Figure 1.5, the graph of the results is given. What is interesting to see is that there is a sharp decrease in the percentage of correct answers over a certain level of complexity. This indicates the limits of the number of concepts students can handle at the same time.

The way you process information differs from person to person. Before information is stored for about 30 seconds in your working memory, the information needs to be processed by your senses. Here again differences occur. Some people prefer visual information, others prefer auditory information, and a third group prefers kinesthetic or touch/ tactile sense information. This preference can easily be determined in speech patterns from people. Something like: "I can see it clearly" now indicates a visual preference, while "I keep telling myself I can do it", would be auditory. "I feel tense about this problem" would be kinesthetic. If you listen to people talk, or when you read something they have written, a pattern emerges. Most people have a primary and a secondary preference. It makes the way information is provided to them important.

Consider for example the following. When you walk to the cellar to get something, you can't remember what it was. When you walk back to the kitchen and

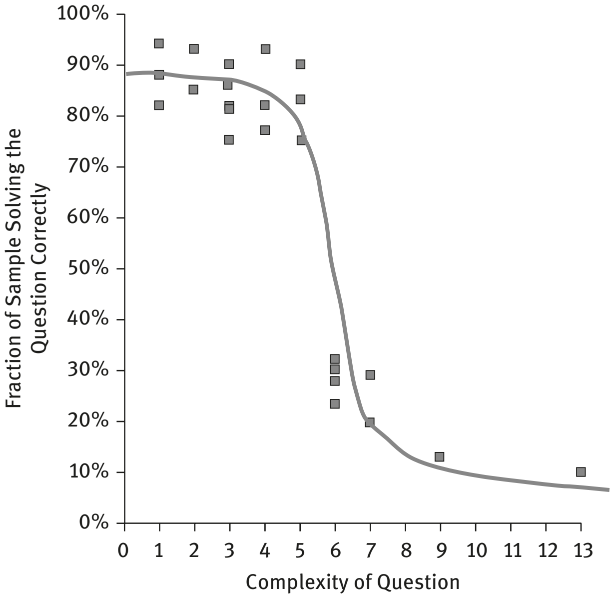


Figure 1.5: Results of students answering questions about the mole, adapted from Johnstone (1997).

arrive there you remember again what it was. In that case, memory was linked to the place you were. An anecdotal example happened in 9th grade, when a teacher in physics recalled some theory about velocity. Students denied any knowledge, while he was sure they were familiarized with the subject in 8th grade. So he talked to the teacher from that year and asked her about it. She confirmed students should know about this. When confronted with this, students still denied any knowledge. Finally, last year's teacher decided to confront the class. When she entered the classroom, the students went something like:' Oh did you mean that?' Their knowledge was clearly linked to the teacher and could not be retrieved in another manner. Clearly this type of tactile or positional information can also be stored and linked to other knowledge.

Robert Mayer (2009) has used Baddeleys Model and found there are basically two parallel working memories, one for words and one for pictures.

What Mayer's model indicates is that you have two types of working memory. One is focused on symbols and images, the other is more focused on verbal information. His conclusions are that in order to optimize information processing, the information in both memories should be aligned. His model is depicted in Figure 1.6.

Aligning the information has become more and more important with the development of PowerPoint, and the use of PowerPoint slides. It is the main reason why reading a PowerPoint slide aloud does not work (if you want to see more problems in

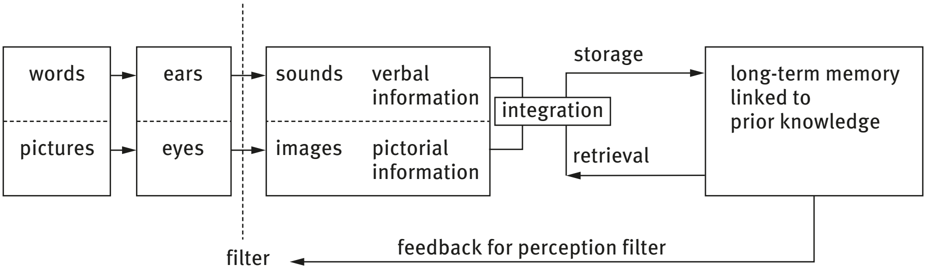


Figure 1.6: Learning model according to Mayer (2009), adapted from publication.

using PowerPoint, see https://youtu.be/Iwpi1Lm6dFo). People read quicker than you can talk. The result is that your information is scrambled for your audience. But also in books and papers visual and verbal information needs to be linked. Papers with a massive number of graphs for example become unclear when the text is no longer clearly aligned with the illustrations. Graphs with too many variables become unclear because of the same reasons.

When storing information into the long-term memory, it will be linked to existing knowledge. When this new knowledge has a good fit, knowledge is extended, chunking may occur. The more knowledge you have, the easier it becomes to extend this knowledge.

Sometimes the fit of new information to existing knowledge is less well, it may even be a misfit. Misconceptions occur. For the learning process, it is extremely important that these misconceptions are diagnosed and remedied as soon as possible.

In some cases, no prior knowledge can be found to link to. In that case, the storage and learning process of this type of learning takes a lot of energy and time. Examples are the learning of the names and abbreviations of the elements. Often retention is difficult and knowledge can be lost very easily, especially if this new knowledge is not used soon after learning. As indicated earlier, mnemonics can help learning these.

- In teaching, several activities may help in fitting new knowledge to existing knowledge.
- Activating existing knowledge is one of the first. Finding out which prior knowledge exists about a concept will demonstrate possible prior misconceptions. It will also show gaps in knowledge that need to be remedied first.
- Chunking knowledge, grouping concepts into a larger whole, is also one of the objectives of teaching, making it possible to extend knowledge further.
- Elaborating existing knowledge, starting from the knowledge that exists, and adding more detail or other aspects to that specific knowledge also help.
- Making schemas demonstrating the relationships between concepts is also a way of improving and increasing knowledge.

1.7 Deep-level versus rote-level learning

As argued in the previous section, meaningful learning occurs when new knowledge can be linked effectively to pre-existing knowledge. Rote learning occurs when no relevant concepts can be found in existing knowledge. The result is an arbitrary verbatim incorporation of this new knowledge. This has led to a model developed by Ausubel (Novak, 1978), about the difference between meaningful, deep-level learning and rote surface-level learning.

In an article written by Novak (1978), one of Ausubel's co-workers, this distinction between rote learning and deep-level learning is linked to forms of teaching and thus can be used in the design of education. Figure 1.7 is adapted from the article to demonstrate this relationship.

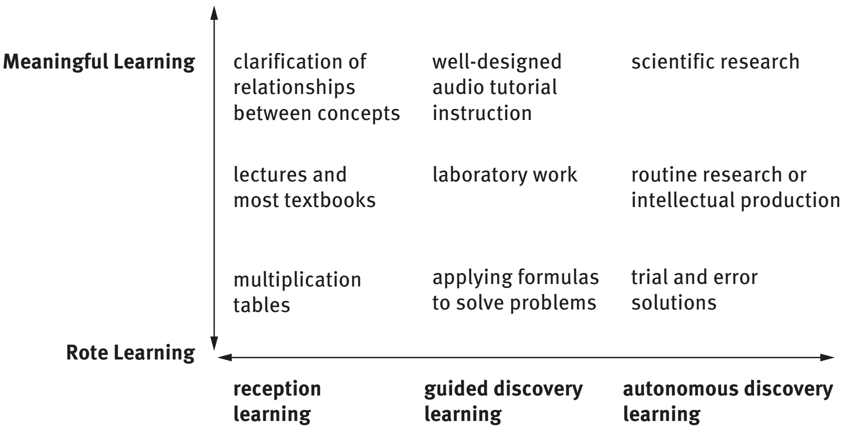


Figure 1.7: Relationship between teaching methods and rote and meaningful learning (Novak, 1978).

These forms of teaching are directly related to the cognitive theory discussed in the previous section.

1.8 Basic principles for teaching

Teaching and learning is changing, in that the focus of teaching is shifting from the teacher towards the student. The learning of the student has become much more the focus of attention. This has led people to formulate basic principles for teaching. Johnstone, for example, a researcher in organic chemistry in Glasgow, has formulated a number of principles (Johnstone, 2010) for teaching and learning. Vosniadou is a member of the international bureau of education and has written a set of activities, based on educational theory (Vosniadou, 2010). These principles are summarized in Table 1.2. They are all related to the activities given in Section 1.6.

Table 1.2: Basic principles for (science) teaching by Vosniadou and Johnstone.

Johnstone	Vosniadou
	Active involvement of the students
	Cooperative work, social participation
	Context-oriented meaningful work
What you learn is controlled by what you already know and understand	Relating new information to existing knowledge
There should be opportunity given to teach (you don't really learn till you teach).	Effective and flexible strategies
How you learn is controlled by how you have learned successfully in the past	Self-regulation and reflection
There should be room to create, defend, try out, and hypothesize	
If learning is to be meaningful, it has to link on to existing knowledge and skills enriching and extending both.	Restructuring prior knowledge
Students should consolidate their learning by asking themselves about what is going on in their own heads.	Understanding rather than memorization
There should be room for problem solving in its fullest sense to exercise and strengthen linkages.	Transfer knowledge to new situations
The amount of material to be processed in unit time is limited.	Time for practice
Cognizance should be taken of learning styles and motivation.	Account for individual differences
Feedback and reassurance are necessary for comfortable learning, and assessment should be humane.	Create motivated learners

These basic principles and activities will actually help your students to learn easier and better.

1.9 Motivation of students

There are many motives for students to take a course. In some cases, courses are mandatory and part of a curriculum. In other cases, courses are elective. In both cases, it is important that you motivate students to learn and achieve the learning objectives you have set.

There are several theories about motivation (Dykstra, 2018) that play a role in higher education. Research has been done on what defines inspirational teaching (Derounian, 2017). However, there is no clear recipe to give for designing an inspirational course.

There are certain factors to take into account though.

Intrinsic motivation is one key issue. This may be influenced by several factors. One of these is the background of the students in your institution. Students in Oxford are different from students attending a technical university like the University of Delft, where engineering is a main focal point. This gives rise to different intrinsic motivations of students. If your course is mandatory, like a general chemistry course for engineering students, or medical and dental students, intrinsic motivation will differ.

Another key factor is self-efficacy. This is the idea that students feel confident enough that they are able to follow the course and are able to achieve the learning goals. In terms of Vygotsky, the content of the course should be within their zone of proximal development.

The level of your students depends partly on entry requirements of your institution.

Extrinsic motivation is where you come in as a lecturer. You can motivate your students in a number of ways. Being passionate about the content you teach about, encouraging students who are having difficulty learning, being entertaining in your lectures are some of the factors that are mentioned (Derounian, 2017). Other factors are, involving students in the lecture by cooperative learning (Bowen & Phelps, 1997) and peer review, demonstrating why students have to learn certain content, by relating the content to your own research. The last means shows students why they need to know things for further studies. Especially in mandatory courses this helps motivating your students.

In a “general chemistry” course for science students (no chemistry majors) is an important issue. If you can demonstrate why it is important for a medical or dental student that he is aware of pH and buffer capacities, they will be more motivated to learn that. In the course content, you might consider teaching a general chemistry course for medical and dental students, and a different one for engineers. The chemical concepts that are important to them overlap to some extent, but quite a few are completely different.

One final issue is giving the students structure. Demonstrating clearly what is expected from them. It is vital to be clear about assessment. Especially freshman in their first year have problems adapting from secondary education to higher education. Being explicit about what they are supposed to themselves, and also monitoring what they are doing, giving regular feedback help in their motivation.

1.10 Design of education

The above is only a short introduction into pedagogy and learning theory. There is a lot more information available. There is too much literature about the theory of learning to be able to point you to a specific book.

As indicated above, knowledge about learning should influence the way you design your education.

There are many learning theories around that can be used when you decide to teach something to a class. What is important is that you choose an appropriate teaching method fitting to the subject you wish to teach, sing the tools that go with the chosen methodology, which can be lecture-based teaching, skills-based teaching, inquiry-based teaching, individual or group teaching.

2 Designing a course

When you start your career in the academic world, you will be asked to teach courses.

On your appointment at a university, you will be allotted research time and teaching time. Normally as a PhD student you will have given lectures as part of a course, you will have assisted during a laboratory course, or worked as a lecturer in seminars or tutorials. Some universities will have courses for this type of teaching assistance.

Being responsible for a whole course is a different matter. The number of students you will be responsible for is an important factor. Graduate courses often have between 10 and 30 students, while introductory courses at the undergraduate level may involve more than 1,000 students. It is obvious that the second one takes a lot more organization than the first. Normally you will be eased into education, first as a partner in a course and in a later stage as the coordinator.

When working on a course, the time spent on a course is always a discussion between you as lecturer and the university administration. In general, the time allotted for teaching is tight. You will need at least 140–160 hours for a normal course. This is time allotted for the whole process connected with a course: from designing, teaching, assessing to evaluating a course. In Table 2.1., an indication of needed times for activities is indicated. When you start teaching, you will need more time for the whole process. The better organized a course is, the less time it takes you to lecture and coach your students.

A course is generally designed using a plan–do–check–act schedule, see Figure 2.1.

An important factor is the half-life time of a course. In general, a course can be given three to five times without a major revision. Conditions change in that time. Pre-requisite courses may have changed, secondary education has a tendency to change every 5–10 years. The knowledge and skills of incoming students will have changed; sometimes dramatically. On the other hand, courses that use your course as a pre-requisite may have changed their requirements. A thorough evaluation of a course will help you when you start setting up a curse for the second or third time.

2.1 Student study time

A major boundary is the organization within the university. Some universities have a semester system, others use quarters. Some universities, especially in Europe, have a system in which courses are taught consecutively. Each course will get allotted 3 weeks, in which the students are only working on that course. Others will have three or four courses running parallel in a semester or quarter.

The normal size of a course will be about 140 hours of student study time, which usually is 5 credits in most European systems. This is called the European Credit Transfer System, in which each credit is 28 hours. Students take 60 credits per year. This leads to a total number of 1,680 hours of student study time in an academic year of 41

https://doi.org/10.1515/9783110569582-002

Table 2.1: Indication of time needed for designing and teaching a course.

Activities	Indication of time needed	Activities
Design	40 hours	Scheduling, making study guide etc.
Lecturing	40 hours	2 hours lecturing + 2 hours preparation
Tutorials	40 hours	2 hours tutorial + 2 hours preparation
Assessment design	8 hours	Designing assessment, peer review, marking scheme
Assessment marking	30 hours	About 20 minutes per student
Evaluation	8 hours	Design questionnaire, evaluating answers, writing improvement plan

Figure 2.1: PDCA-schedule.

weeks. In the United States, a credit system is often used in which a credit is linked to contact time. One credit corresponds to one 50-minute lecture and should involve about 2 hours of study time. Over a semester of 15/16 weeks, 1 credit amounts to about 40–45 hours. The normal size of a course is 3 credits, which is 120–135 hours. The number of courses is determined by the students. Some students take more courses in a semester if they can, others take less.

In Europe, you will need 180 ECTS to obtain a bachelor degree. In the United States, this will be between 120 and 180, depending on the credit system used.

Lecture time will differ depending on the system used. A regular course will have at least 10 two-hour lectures and 10 two-hour tutorials. For a lab period, you normally need at least 3 hours. The remainder of the time allotted to a course is study time for the students. The way students use this study time can be directed by giving them assignments and homework (Figure 2.2).

Figure 2.2: Student doing homework.

2.2 Design

When you start thinking about the design of a course, there are quite a few criteria that should be taken into account:

- The level at which the course is taught:
  - level of incoming students
  - required teaching goals for other courses
- The credits connected with the course:
  - the time available for teaching
  - time available for learning
- Available facilities:
  - available lecture rooms
  - available laboratories
  - available Internet facilities
  - number of Teaching Assistants that may be involved
- Number of students

All these criteria need to be taken into account when designing a course.

2.2.1 Model used for the design

For the design of a course, several models may be used. In this book, the so-called model of educational reconstruction (Duit, Gropengießer, Kattmann, Komorek, &

Parchmann, 2012) is used. It was developed at the IPN in Kiel combining quite a bit of background research on education.

The backbone of the structure is that after the science content for a course is determined, the subject matter is clarified and its educational significance is determined, this is related to research on teaching and learning. It is combined with the perspective of the learner and the teacher's view and conceptions.

These three factors combine into the design and evaluation of teaching and learning environments, in which these main ideas are combined. In Figure 2.3, the relationship between the three ideas is depicted. The first step in the process is determining and formulating the science content, and formulating the content in desired learning outcomes. These learning outcomes play a central part in the actual design of the course. The link between science content and educational research has been called Pedagogical Content Knowledge (Loughran, Mulhall, & Berry, 2004)

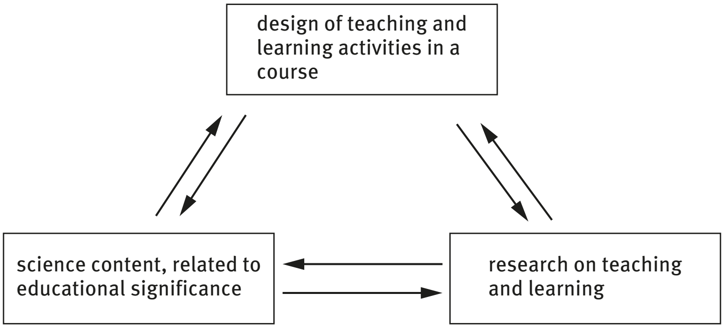


Figure 2.3: Model of educational reconstruction.

The model makes clear that not only the science content is important in determining the content and design of a course. Knowledge and ideas about the learning process is just as important. It is also clear that evidence-based education design is key to successful education activities (Cooper, 2014). Discipline-based educational research is the base for successful courses. This type of educational research is slowly emerging and provides background for the design of courses. In Chapter 1, basic theories that lie at the base of this type of research have been discussed. In databases like ERIC and EBSCO, articles can be found about a wide range of course subjects.

When starting the planning of a course, four questions are important in the design.

As far as the scientific content is concerned, the first question should be:

Why does a student have to learn this?

What exactly is it that he has to learn?

Then the question is, What is the best way to learn this scientific content?
Finally, which instructional methods are to be used in order to let the student learn the content.

This means that the science content has to be analysed first. The main ideas of the science content need to be formulated. Then a decision can be taken on the main ideas of the content to be instructed.

2.2.2 Science content

So the first step in the design of a course is choosing the science concepts you want the students to learn about. You will be either in a position in which you take over a course from someone else, or you will be the first to teach a particular course. In the last decade or so, new undergraduate courses about green chemistry, for example, have started up. In graduate schools, introductory courses in your own field of research are very often set up. In that case, you will be completely free to decide the content of the course. Courses you take over in undergraduate often have some history of topics to be learned by the students. Especially those that play a role in other majors, like a general chemistry course, will have some requirements as far as science content is concerned. It is important however that you decide yourself what the scientific concepts in the course will be. In a number of cases, these courses will be based on textbooks that have been around for quite a while. When you take over a course, it is important to orient yourself of other textbooks and find one that will fit with your ideas about the teaching and learning of the subject matter.

2.2.3 Place in the curriculum

You will need to determine what the place of your course is within the curriculum of your institution, and how it contributes to the learning goals of the whole curriculum. What kind of knowledge and skills can you expect your students to have when they enter the course? This is something you will need to check at the beginning of a course. You will be surprised at the way students will reproduce the knowledge you expect them to have. It is important to formulate which prerequisite courses the students should have taken before they can take your course, especially if you have students attending from different study majors.

What kind of knowledge and skills are students expected to have when they leave your course? You should be able to explain why it is important that students take your course. For your colleagues, it is equally important that they are aware of the learning outcomes of your course.

2.2.4 Deciding about the science content

The first step in the process of design is to formulate the learning goals in terms students and others can understand.

The position of the desired learning outcomes has been formulated by Biggs (1996).

His main idea is called constructive alignment, and is described in Figure 2.4.

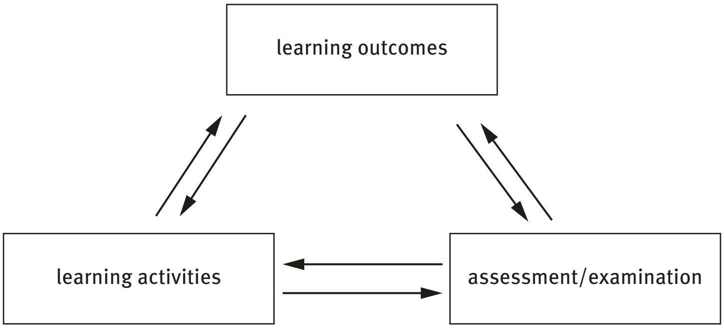


Figure 2.4: Constructive alignment according to Biggs (1996).

From the science content, the desired learning outcomes are formulated, which are then linked to learning activities. With this last term, the actual activities like lectures, seminars, tutorials, labs are meant. Finally, the assessment is linked to both the learning goals and the learning activities.

Normally you will start by formulating a fairly general goal for a course. In the case of green chemistry for example, ‘learning about basic principles of green chemistry, applied to concrete examples’ would be a generally formulated learning goal.

This general goal will need to be extrapolated into more concrete concepts. Again, using the same example of green chemistry, concepts like:
- The twelve principles of green chemistry
- Atom economy
- E-factor
- Sustainability
- Life cycle analysis
- Reaction media
- Catalysis

will be chosen.

For each of these elements of broader scientific concepts, you should ask yourself a number of questions:

– Why is it important that students learn about this concept?
– What do students need to learn about this concept?
– Which aspects of this concept need not be learned at this time?

These questions are based on research by Loughran et al. (2006).

They help in determining precisely what you expect students to learn about a specific concept in terms students and your colleagues can understand.

2.3 Formulating learning goals

You have to be very specific about what students should be able to do with the concepts you have chosen. You may want the students to be able to reproduce a definition or a concept for example or you want them to be able to calculate something.

It is very important that you do not set the goals too high or too low, otherwise students will not be able to work on the goals (Locke & Latham, 2002). In terms of Vygotsky (1978), the goals should be within the 'zone of proximal development' of the students.

You will have to formulate your learning objectives in an active form which is often called SMART:

S: Specific, meaning it should relate to one concept
M: Measurable, should be possible to assess whether or not objective has been reached
A: Attainable, should be possible to attain
R: Relevant, should be relevant for the course
T: Timely, should be able to achieve in the given time

An example of a SMART formulated learning goal could be:
– Students should be familiar with the 12 principles.

An example of SMART formulated one could be:
– Students should be able to reproduce at least four of the twelve principles of Green Chemistry.

The first one is not measurable. The second one is.

When formulating the learning goals, you can also indicate the level of knowledge students should attain. Several people like Bloom (Anderson & Krathwohl, 2001) and Krathwohl (Anderson & Krathwol, 2001) have formulated levels of knowledge.

A fairly simple distinction in levels of knowledge that is easily applied is the following:
– Reproduction
– Apply in a known situation

- Apply in an unknown situation
- Integrate with other knowledge

Some examples for Green Chemistry:
- Students should be able to calculate the E-factor for a given reaction
- Students should be able to select an appropriate catalyst for a given reaction
- Students should be able to evaluate a given process in terms of environmental impact.

To make this distinction you can use different types of verbs describing what students are expected to be able to do. An example is given in Table 2.2.

Table 2.2: Verbs related to levels of knowledge.

Level of knowledge	Associated verbs
Reproduction	List, identify, summarize
Apply in known situation	Classify, calculate, select, evaluate
Apply in unknown situation	Calculate, determine, assemble, check
integrate	Design, reflect, create

2.4 Planning the course

When you start planning the course you need to combine what you know about the learning and teaching process with that of the learning goals you have formulated. You will need to design a coherent set of educational activities that will let students achieve the learning goals you have set them. Normally at other universities similar courses as the one you will be coordinating will have been developed. It is often very helpful to look at these courses. With the development of the web, it has become a lot easier to share this type of information.

Planning the course involves more than just planning contact time. It involves setting up a study guide as well. This can be an online guide or paper guide. It also involves planning the assessment and marking.

2.4.1 Learning activities

After you have formulated your learning objectives, you can start linking your objectives to learning activities. There are a number of standard learning and teaching tools available:
- Lectures
- Tutorials

– Group work
– Homework or individual study
– Lab work
– Computer work
– Other activities

It is up to you to decide how you can help your students to attain your learning objectives. Very often lectures are used to give some structure to the course. The other activities are basically tools to help learn and incorporate new knowledge and skills. Especially problem-solving skills need adequate practice in exercises and problems.

In order to determine how a specific learning goal can be achieved is by asking yourself the following questions:
– What are difficulties/limitations connected to teaching this goal?
– What do you know about students thinking concerning this goal?
– What other factors have an influence on your teaching of this idea?

The difficulties and limitations are not always cognitive. They may also involve the number of students you are dealing with. The facilities you have at your disposal can also be a limiting factor. The type of lecture hall available is one of them. But for example, the computer software available to you and your students is important. If you want more than standard programming like Excel or similar, but you want more advanced statistical software or something like 'Chemdraw' (Morsch & Lewis, 2015) or 'Hyperchem' (Fountain & McGuire, 1994), you will need to apply for that software to become available for your students. Another factor is the number of Teaching Assistants that will be assigned to you when teaching this course. What lab facilities are available is also an important question.

If you look at Table 2.1, it becomes clear that there is a relation between the number of students and some of the activities. For lectures the size of the lecture theatre is the limit. For tutorials, the optimum number is about 24. In a regular labroom you can have 8–12 students at the same time. You will also need at least one TA for such a group.

An easy way to relate goals to activities is to construct a table. In Table 2.3, an example is given for part of a green chemistry course.

In Chapter 3, the learning activities are discussed more fully.

2.4.2 Time schedule

Next step is to make a time schedule in which you assign times, rooms and personnel to activities. Normally you will have to discuss things with the facilities department of your faculty. Here again things depend on the type of schedule your university is working with. You either have 3 weeks full time or 12–15 weeks part time, in which

Table 2.3: Relation between learning goals and learning activities.

Learning activities	Time involved	Learning goal 1	Learning goal 2	Learning goal 3	Learning goal 4
Short description of goal		12 principles of green chemistry	Atom economy	E-factor	Sustainability
Lectures (total 8-10)	2 x 45 minutes	Introduction and discussion about impact	Introduction and demonstration of effect		Discussion of principle, UN sustainable development goals
Tutorial (exercises and problems)	60 minutes		Exercises and problems		
Literature assignment					Prepare presentation About one of the UN goals
Lab work	2 sessions of 180 minutes in the lab	Compare two ways of synthesis of adipic acid			
…..					
…….					

normally the last two are devoted to study time and exams. In the second case, the students will have two other courses at the same time. This means you have a maximum of 14 hours of student time per week, including self-study time.

In Tables 2.4 and 2.5, examples are given for a possible green chemistry course.

Table 2.4: Incomplete example of a schedule for a 3-week course.

Week		Monday	Tuesday	Wednesday	Thursday	Friday
1	am	Lecture 1, room, lecturer	Practical 1, room, TA	Lecture 2, room, lecturer	Practical 2, room, TA	Lecture 3, room, lecturer
	pm	Tutorial 1, rooms, TAs	Lab reports and prepare for practical 2	Tutorial 2, rooms, TA	Self-work on presentation	Self-study
2	am	Lecture 4		Lecture 5		Lecture 6
	pm					
3	am	Lecture 7		Lecture 8	Prepare for exam	Prepare for exam
	pm				Prepare for exam	Exam

Table 2.5: Incomplete example for a 12-week course (only contact time is scheduled).

Week	Monday	Tuesday	Wednesday	Thursday	Friday
1	Lecture, room , lecturer		Tutorial, rooms, TAs	Practical 1, room TAs	
2	Lecture, room , lecturer		Tutorial, rooms, TAs		
3	Lecture, room , lecturer		Tutorial, rooms, TAs	Practical 2, rooms, TAs	
4	Lecture, room , lecturer		Tutorial, rooms, TAs		
5	Lecture, room , lecturer		Tutorial, rooms, TAs		
6	Lecture, room , lecturer		Tutorial, rooms, TAs		
7	Lecture, room , lecturer		Tutorial, rooms, TAs		
8	Lecture, room , lecturer		Tutorial, rooms, TA's		
9	Lecture, room , lecturer		Tutorial, rooms, TA's		
10	Lecture, room , lecturer		Tutorial, rooms, TA's		
11			No classes		
12			Exam		

There is little research indicating whether consecutive courses yield better study results than the parallel set courses. Both have their obvious advantages and disadvantages.

2.5 Supporting and monitoring the learning process

While the course is progressing, you will need to monitor the students. You need to get some idea about the extent in which they have learned things. You need to plan these into the program. When things don't go exactly as you plan them, you need to be able to improvise.

In Chapters 3 and 4, several activities are described that you can use to monitor the students. Small tests before and after a lecture, interactions during the lecture, homework handed in, lab reports are all indications of the progress of students. Letting the students give presentations helps both the student giving the presentation and the listeners. In the green chemistry example above, presenting one of the UN sustainable development goals (Way, 2015) and relating the goal to a specific set of criteria would be a useful exercise.

Reviewing an article of course is also one of the tools that could be used to assess the students' understanding. In general, activities in which the students interact with the content of the course are usable. Training them toward what is expected of them, and also helping them along the way, is the main idea. As this is very often an individual process, you need to be able to give specific feedback to each student about his progress. Some form of online interaction is a requirement to optimize this exchange. Videos taped on a mobile phone can be very helpful to judge the skills of students. A tape of a short pitch, or some lab skill, can help identify weaknesses as well as strengths. With the communication channels that are available at the moment, this is very easy to do. YouTube offers this possibility, for example.

2.6 Literature used in the course

Normally you will be using background literature for your course. For most undergraduate courses textbooks are available. Choosing a textbook may be difficult as there may be many textbooks available in certain subjects. The most important criterion for a textbook is that it fits with your own style of teaching. You can also consult colleagues about the use of textbooks. Publishers will give you online access to their textbooks, but will also send you a hard copy if you wish.

If the textbook matches your teaching style, and reinforces the student behaviour you wish to stress, it will reinforce your own teaching. In general chemistry, for example, you may find contexts important as well as the link between the macroscopic scale and the atomic/molecular scale. In problem solving you may wish that a systematic problem-solving approach is used. In that case, the book written by Silberberg and Amateis (2015) is the obvious choice.

For most graduate courses, you will need to compose a reader, containing review articles or research articles as background material. At that level, it is the normal source of information although sometimes textbooks are available. You can of course decide to write your own text.

2.7 Communicating with the students

In the past, this was done through a printed syllabus. Nowadays the internet is used as a means of communication. Software tools like Blackboard, Moodle and (see figures 2.5, 2.6 and 2.7) are platforms specifically designed for educational purposes (López, Sáenz, Leonardo, & Gurtubay, 2016).

Normally your university will have one of them available.

If you are not familiar with the offered software, it is advisable to take a course (Tofan, 2009) Most IT-departments will offer a course on the software used. It's

Figure 2.5: Logo of Blackboard.

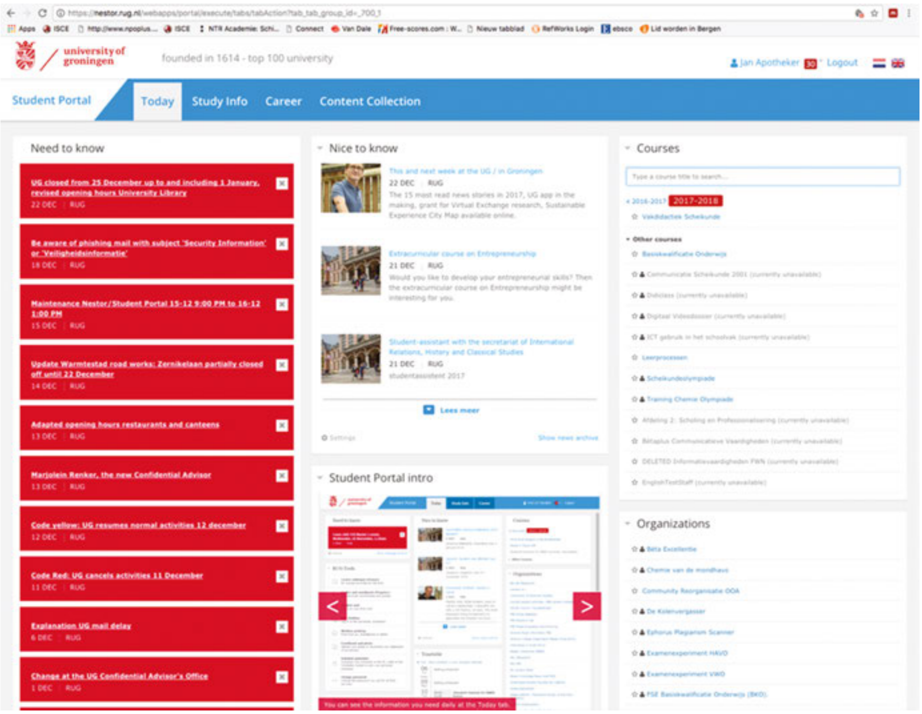


Figure 2.6: Screenshot of the author's opening page of blackboard.

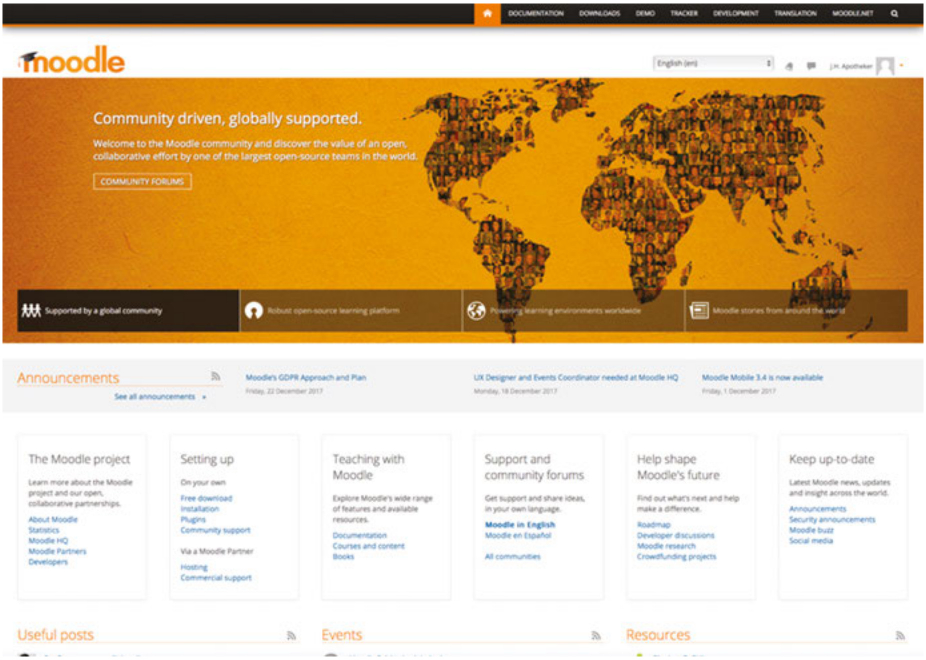


Figure 2.7: Screenshot of the starting page of Moodle.

important to understand all the extras this software offers. You can have your students take an online test for example. They can hand in homework, they can discuss their presentation and get peer feedback from their fellow students, or from their assigned tutor or you.

These learning platforms have evolved enormously over the past 10 or 15 years or so. It changed from a fairly simple instrument to communicate the schedules and goals of a course into an instrument that makes communicating with your students a lot simpler.

In these electronic learning platform, you can provide all necessary course information, including things like:

- Learning goals
- Course schedules with teachers and rooms
- Copies of all slides
- Literature needed for the course
- All assignments, including exercises and problems
- All lab-related files
- Lis of participating students
- Assessment schedules
- Contact information for all teaching staff

– Videos of the lectures (Vasquez-Abad, 1999)
– Assessment procedure

This is also the information you will need to give in a study guide, should you wish to publish a study guide. Actually a lot of lecturers include the study guide as a pdf file in the E-Learning platform.

By now, there are many other tools for education available online. Google has a large set of relevant tools, but there are many more apps and software available.

2.8 Assessing your students

You will need to plan the assessment of your students. Students will need some type of grade when they finish the course. In Chapter 4, assessment methods will be discussed in more detail. In the planning phase, you will need to allocate time for assessment during the course. In the student guide or course syllabus, you need to explain exactly what is expected from the students and how they will be assessed. In the green chemistry example, there was a final exam, in which all learning goals were tested, but there was also a lab design as well as a report. Finally, there was a presentation. How these three yield a final score ((score on lab report)*0.2+(score on presentation)*0.1+(score on final test)*0.7 = final score) needs to be made public. You will also need to plan how students will be able to check the way you have graded the different products. For that you will need to have a grading template or marking scheme. Normally, a session is organized in which the final test is discussed, together with the grading model. As grading is open for individual interpretations (Bloxham, den-Outer, Hudson, & Price, 2016), students should be able to discuss the grading of their work.

2.9 Improving the course

Before you start teaching your designed course, you will need to set up a system of evaluation. You will need to find out whether or not your students reached your learning objectives. The assessment you have integrated in the course is just part of the evaluation. You will need to interact with the students either directly face-to-face or through questionnaires how they experience the learning activities you have designed. Based on their and your own experiences, you can adapt the course.

In order to keep track of your own experiences as well as those of the Teaching Assistants, you will need to take evaluation notes at the end of each activity you have executed.

When you take over a course, the evaluations of previous years give you important information about areas in which improvements of a given course are welcomed.

2.10 Ethics in education

Within the university there will be some sort of academic code of conduct. This type of code of conduct mainly deals with scientific integrity and also with subjects like data collection, use of references and so on. In education, extra guidelines are in force, especially dealing with the relationship between teacher and student. In this relationship in which the lecturer is more powerful than the student, extreme care must be taken that no unethical use is made of this relationship. There are other considerations. Assessments must be based on impartial considerations. Individual bias should not play a role in assessment.

It is very important that in the planning of your course procedures are very clear. They must be the same for everybody. Care should be taken that any form of bias is excluded as much as possible.

It is extremely important that the assessment of students is well documented. That is why a marking scheme used for scoring a written assignment is important. These should be saved for a period of time, in case they need to be produced in some procedure.

Students should have the opportunity to check and question the assessment of their work. In a written exam, this is fairly easy. When scoring a presentation, or when a student takes an oral examination, this is more difficult. You will need a set of criteria on which you base your score of the student. It is best to have some type of form that can be used to determine the students' score. This scoring form needs to be discussed with the student as soon as possible, after the presentation. Often it is best to have an observer present during an oral exam or presentation. A wise precaution is to tape the session, so the presentation or oral exam can be reviewed by others.

The procedure to be used in case there remains a conflict between the lecturer and an individual student should be made clear in the study information provided for the course. Most universities will have some sort of exam committee to which the student can appeal in case he feels he has been treated unfairly. In such cases, the exam committee will need all documentation about the assessment that is available. In most cases, a hearing in which both lecturer and student are present will be held. The focus of the exam committee will be to reach a solution for the conflict between student and lecturer. In case that cannot be reached, they will issue a binding verdict.

In chemistry, discussions are going on about the use of chemical knowledge, like the 'The Hague ethical guidelines' (OPCW, 2015). In this type of guidelines, the way chemical knowledge is used is the subject of discussion. The responsibility of anybody having chemical knowledge in using that knowledge in an ethical way is an important issue. It is something to be discussed in education. Students acquiring chemical knowledge should be aware that chemical knowledge can also be used to produce substances that are harmful to people, like chemical weapons and drugs.

At some time during their education, students need to realize they have knowledge that not only can potentially be very positive for society but can also be harmful. By confronting the students with these ideas, they can think about their own position in issues like this.

3 Lecturing in a chemistry course

3.1 Introduction

When you design a lecture to be given as part of a course, you will need to pay attention to both the actual lecture itself and the activities you expect students to do before and after the lecture. You can expect students to prepare for a lecture. Just asking them to read a chapter before they come into the lecture is too vague. You need to be more specific. This also goes for activities after the lecture. This can be homework, making problems or exercises, or extra reading. It may also be in preparation for a tutorial session.

These aspects will be discussed in separate sections in this chapter.

3.2 Lectures

Lectures are often seen as the most important part of the educational process in a course. They are seen to form the backbone of the whole course. Traditionally they have been used as the main form of instruction. At present their character has changed quite a bit. Instead of a monologue they are now much more interactive with students. Instead of listening and sitting back passively, students now have to be a lot more active. Where in the past you might read a newspaper in a lecture hall, but that time has changed now. However, mobile phones still distract students (see Figure 3.1).

The role lectures actually play in the learning process is perhaps not as large as other learning activities in the course. Students have to play an active role in their own learning process. In tutorials and in the lab, this is easier to achieve than in a lecture.

Lectures normally have two main functions. They are the place for interaction between you as a lecturer and the students. For one you can provide information about the course and the structure between the activities, as well as guide the students. It is also a place to introduce and discuss new concepts and relations to the students and show how they play a role in science.

A lecture is normally part of a series of lectures you plan to use to introduce the science content of a course. In that sense, it is leading for the other activities you plan during the course. The lectures give you an opportunity to interact with students on a regular basis.

3.2.1 Interactivity

The scope of a lecture has evolved over time. Even in groups larger than the regular 120 or so, going up to the maximum size of a lecture room of maybe 300, interactivity is now a keyword. There are several ways in which you can interact with larger groups.

https://doi.org/10.1515/9783110569582-003

Figure 3.1: Students in lecture.

Most of these activities are based on the principles of cooperative learning. Johnson and Johnson (1999), Slavin (1995), Kagan (1990) and others (Aronson & Patnoe, 1996) have developed cooperative learning activities that induce students to work together actively on problems and exercises, improving their knowledge and guiding their learning process. All these activities in the lecture theatre are meant to activate the students. In cooperative learning, one of the main features is that students work together during their learning process. This stimulates them and generally induces them to form a deeper knowledge of the subject studied. In cooperative learning, which was developed in the 1980s and 1990s, these activities were introduced without technology.

Mazur (1997) has introduced the idea of peer instruction, in which multiple choice questions play a major role.

One of the goals of Mazur in his methodology is that he wanted students to discuss among each other. So he posed a multiple choice question in which he wanted to check whether one or more concepts were understood. An example is given in Figure 3.2.

Mazur first allows students think in silence for may be half a minute and then makes an inventory of the answers, by hand raising. He writes the inventory on the blackboard and asks the students to explain to their neighbours why they chose their answer. After about a minute of discussion he makes another inventory. He may now ask some students to indicate why they chose for A, B, C or D. He then briefly discusses the correct answer B.

Question

- Solution A is a solution of HCl, solution B is a solution of HAc. Both have a pH = 3.0, and a volume of 1 L. Both are diluted to 2 L. What do you know about the pH of both solutions?
  - A: The pH of A < the pH of B
  - B: The pH of A > the pH of B
  - C: The pH of A = the pH of B
  - D: You need more data

Figure 3.2: Example of a peer review question.

Mazur's main concern was the way students learned in his class room. He found students had little or no understanding of concepts. They learned the procedure for solving problems, but did not really understand what they were doing. The design described above forced students to think more actively, deepening their knowledge.

Similar activities are possible. If for example you have just discussed the structure of amino acids in the first part of a lecture, students come back from the break. You could then, at the start-up of the second part of the lecture, ask them an open-ended question. You could ask them to name three characteristics of amino acids. You could let them work in groups of three or four, ask them to write down the answer and hand them in to you.

Especially Kagan (1990) has developed many different activities, all based on interaction between students.

Figure 3.3: Interaction between students during a lecture (source: Flickr).

Some of these are focused on secondary education, and others can be used in higher education. Allowing students work on short problems, having them present solutions as groups, either directly in class, or on paper, works well. One specific way of checking whether your lecture was successful is to ask the students to write down three or four main points of your lecture at the end, if you take these and check to see what they have learned.

About 15 years back or so, clickers were introduced. With the introduction of smart phones and tablets, other means of interaction are feasible (Aslan & Seker, 2017). This makes activities described earlier a lot more easier. Software and apps have been created that will give you an opportunity to interact directly with your audience. Apps such as socrative, kahoot and nearpod are available online.

There are quite a few more if you google on the Internet. “Nearpod” has several options, which make it easy to use. It has certain features that the others do not have (Mattei & Ennis, 2014).

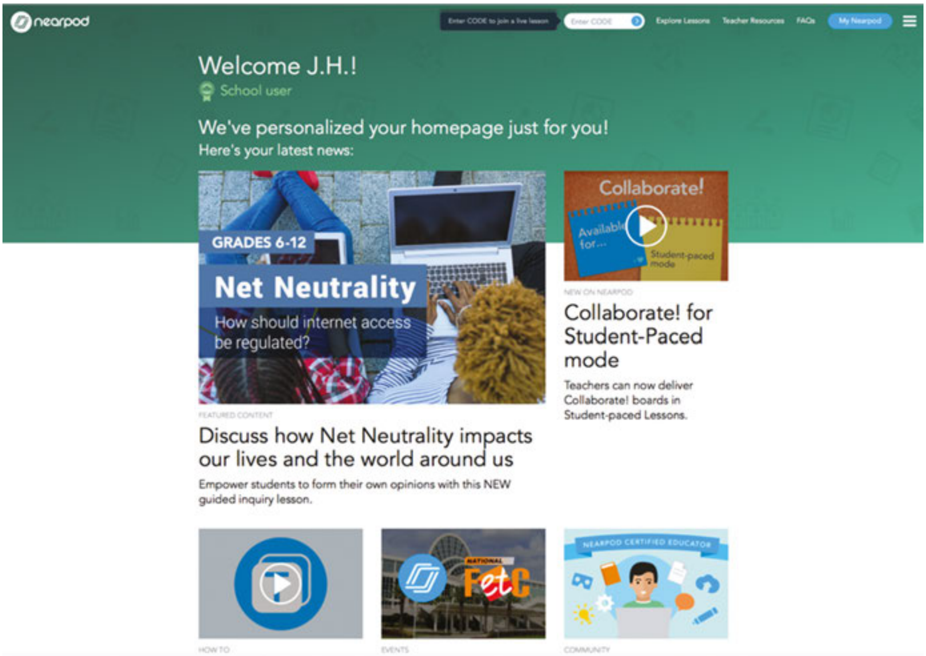


Figure 3.4: The author’s start-up page of nearpod (screenshot made by the author).

Once a PowerPoint or PDF is prepared, it can be uploaded to the website of nearpod. On the website, you can insert slides that contain questions, which can be answered by yes/no or true/false, or you can have multiple choice questions. A special feature is the possibility of open-ended questions where the students get a limited number of characters to answer. It is even possible to have the students draw the answer if you like.

In the presentation, it is also easy to introduce an MP4 formatted video of up to three minutes. Or a particular website can be shared.

In the lecture hall, a tablet or laptop is used as the controlling device for the presentation. Even a smartphone can be used. When you open up the presentation, a four-letter pin code is generated, which should be displayed to the students. Logging in on your presentation with the presenting computer coupled to the LCD projector in the lecture hall will automatically show the four-letter code to the students. Students can either log in through the website nearpod.com, or through a free downloadable app. When a student logs in he/she is asked to identify him/herself. You can have a prepared list ready, or they can choose their own name.

That way you know exactly who is in the lecture hall. You do not have to be in the lecture hall to join the presentation, though. Anybody with the code can join the lecture.

The students will get a view of the slideshow you have entered.

On the device used to open the presentation the number of students that have entered is displayed.

When a poll or question is entered on the slideshow the students see the question and possible answers and can submit their response. On the controlling device, an overview is given of the answers, which can be shared with the group logged in to the presentation.

Students only see a full screen of your slideshow. It takes a specific effort to leave the full screen mode and start doing something else. Having the slides on their own device also gives them an opportunity to zoom in on a specific part of the slide.

There is no real limit in the number of users. You or the institution has to have a contract with nearpod if you want larger groups. The app is free for groups up to 30. At the University of Groningen it was used with groups up to 300.

After you close the session, nearpod sends you an e-mail with an overview of all responses to questions, including activities of the students.

One of the best features of nearpod is that the questions are embedded in the slideshow. Some of the other apps are difficult to link with PowerPoint or keynote. This means you have to leave your presentation go to a website in order to perform a poll.

All of this is of course also feasible using no technology, using coloured cards for voting and so on, but these online apps make this type of interactivity a lot easier to implement.

These apps make it possible to have direct feedback on the learning process of a large group of students. You receive almost instant feedback on the way your lecture is going. It gives you the opportunity to adjust the lecture accordingly.

3.2.2 Design of a lecture

When designing a lecture, Table 3.1 is a good guideline to start the design of the lecture. Especially when you use a textbook it is important to identify the five or six

Table 3.1: Guideline for design of a lecture.

Main ideas	Idea 1	Idea 2	Idea 3	Idea 4	Idea 5
What do I want the students to know about this idea/concept					
What is it they do not need to know about this concept					
Which concepts do they need to know beforehand					
Learning goal					

main ideas/concepts you wish to discuss during the lecture. Six main ideas are about the maximum of new concepts you can introduce to students. It will help you clarify in your mind which points you wish to make during the actual lecture. It is an analogue of what you did when designing the course.

In Table 3.2, a worked example is given of a specific biochemistry lecture, introducing enzymes.

This table fairly defines closely what you wish the students to learn at this time. At a later stage, during a tutorial they will need to work on problems using these new concepts.

In Table 3.3 you will be able to plan a bit more precise what you wish to do.

When you present a concept certain steps should be thought of:

- You need to activate pre-existing knowledge in the context you wish to discuss the new concept.
- Knowledge is not recorded in the long-term memory as a list of facts. There is a branched structure in which knowledge is embedded. Elaboration, linking the new concept to different types of knowledge, makes it easier to retrieve.
- Retrieval of knowledge is linked to a context. That means the new concept should be introduced within the context, or situations it will be needed and used.
- Creating a situation in which it can be made clear why a student needs to learn this new knowledge helps in their motivation.

The average attention span during a lecture is not more than 10 min. You need to consider that. Having a question or something that activates the students at that time relating to what you introduced in the first 10 min will give you an idea how far your ideas came across. It also makes them ready for the next step. Using this type of schedule, you can cover three main concepts in 45 min. That schedule is tight though. With two main concepts, it will be a lot easier to find enough time for a thorough introduction as well as interaction with students. After the break, the attention span of students will be shorter. You need to take that into account. Boredom will easily set in as Mann demonstrated (Mann & Robinson, 2009). Even

Table 3.2: Worked example of a lecture presentation.

Main ideas	Structure of amino acids	Peptide bond	Primary and secondary structure	Tertiary structure and quaternary structure	Active spot
What do I want the students to know about this idea/concept	An organic compound having a carbon atom with both an amino group and a carboxylic acid group, different types of side chains, including polarity/possible H-bonds and sulphur containing amino acids	Amide bond between two amino acids, formation of chains of amino acids, some properties in terms of bonding angles and polarity, H-bonds	Longer chain of amino acids, different lengths, spontaneous folding of amino acids in alpha-helix and beta-plaited sheet	Bonding between cysteine side chains, and h-bond formation, ionic bonds between side chains, to create 3D structure. Combining different protein chains and other molecules in active enzyme	Specific bonding between substrate and enzyme, conformational changes releasing products, reversible and irreversible inhibition
What is it they do not need to know about this concept	No need to know about pH, isoelectric pH, etc.	No thermodynamics or rates are needed now, no relation with protein synthesis	No relation with functionality	No binding within the cell, or to a specific spot	No rates of reactions
Which concepts do they need to know beforehand	Basic organic chemistry nomenclature	sp3, polar bonds, H-bonds		Primary and secondary structure	Basic organic chemistry about bonding
Learning goal	Students should be able to draw the structure of an amino acid, recognize an amino acid	Students should be able to give the chemical equation (in structural formula's) for the formation of a dipeptide	Students should be able to recognize different structures in a protein	Students should be able to describe how a quaternary structure can be formed. They should be able to indicate different regions within a given enzyme.	In a given example students should be able to explain how an enzyme binds specifically with its substrate

Table 3.3: Concrete example of a timetable for a lecture.

Time	Content	Student activity	Teacher activity	Media
0–10	Idea 1	Listening	Presenting	Slides 1–7
10–15	Multiple choice question	Answering and discussion	Analysing answers	Slide 8+ answers/ question
15–25	Idea 2	Listening/ interactive	Presenting/leading discussion	Slides 9–11+ blackboard and chalk
25–40	Question and discussion	Interactive	Leading discussion	Slides 12–15 with questions/problems
40–45	Wrap up of first part		Presenting	Slide 16
45–60	Break			
60–65	Questions		Leading discussion	
65–75	Idea 3	Listening/ interactive	Presenting/leading discussion	Slides 17–20+ blackboard and chalk
75–80	Multiple choice question	Answering and discussion	Analysing answers	Slide 21+ answers/ question
80–90	Idea 4	Listening/ interactive	Presenting/leading discussion	Slide 22+ short video
90–100	Idea 5	Listening/ interactive	Presenting/leading discussion	Slides 22–26
100–105	Open question	Answering and discussion	Analysing answers	Slide 27+ answers/ question
105	Wrap up and announcing tutorials lab, etc. + homework	Listening	Presenting	Slide 28

though he related this partly to the use of PowerPoint without giving handouts to the students, other factors will contribute to boredom. Boredom is easily detected by the diminishing attention during lecture and a lower attendance during the next lectures.

3.3 Pre-lecture activities by students

3.3.1 Flipped classroom

The so-called flipped classroom (McNally et al., 2017) is a technique in which pre-lecture activities are organized, so students can be exposed to content prior to the lecture. One of the main reasons for doing this is to focus in class on higher learning activities. Often a small test or quiz is part of the preparation. The effectiveness of these activities is debated. For a number of reasons pre-lecture activities are important. If you have students with a different background pre-lecture activities will help bring the students to the same starting level.

The idea behind row 3 in Table 3.1 and row 4 in Table 3.2 is to identify which knowledge and skills students should have before coming to the class. In Table 3.2, the biochemistry course will have a prerequisite of a course in general chemistry. Referring your students to the relevant chapter in the textbook used there as well as some problems they should be able to solve will help the students, especially when they come from a different background, as in the case of Table 3.2 (biologists and chemists).

Organizing these activities can be challenging. Very often a quiz is administered through the E-learning environment. This is easy to do. It is possible to organize it in such a way that it is registered whether or not a student has taken the test.

If for example you want to discuss Rutherford's and Bohr's atomic model, students should be familiar with Dalton's atomic model as well as the concepts of protons, neutrons and electrons. They should also be familiar with the concept of potential energy. To determine the way students understand these concepts, simple tests can be administered, with questions like:

What is the charge of an electron:
- *a. +1*
- *b. −1*
- *c. 0*

When a student fails this test, he or she should be given an assignment in which he or she can familiarize himself with these concepts. Another possibility is to have them attend a pre-lecture tutorial, in which these concepts are discussed.

When students go through such a procedure preparing for a lecture, you can be sure all students have the same starting level when they enter the lecture.

Another reason for the flipped classroom is the possibility to discuss more in-depth concepts. In a graduate course, you may require your students to read one or two articles before they come into the lecture. You can then discuss the articles in detail with them going into intricacies that would otherwise not be possible.

One of the problems is that students will try to get away with not preparing for a lecture. If you give students that opportunity that will most certainly happen. That means you will have to actively use the work the students have done, or check that they have prepared themselves as you wished them to do. If you let them get away with not preparing the motivation to prepare for the lecture will drop immediately.

Especially in courses for third or fourth year students or graduate courses this is the case. Very often there is no textbook for such a course. There is plenty of relevant literature of a course. Normally you will want your students to read articles before they come into the lecture. If they haven't done so they need to understand that they can't follow the lecture. Next time they will definitely prepare better. Again, here a small pre-lecture test about the articles will make sure that students have picked up the relevant details.

3.3.2 Mathematical abilities

Mathematical skills seem to be a problem in undergraduate chemistry courses. The 2017 fall confchem (https://confchem.ccce.divched.org/2017FallConfChem) has been focused on mathematics in Undergraduate Chemistry Instruction. This conference is an online conference, in which papers are presented, followed by an online discussion. The theme in the fall conference of 2017 was on mathematical skills in chemistry education. Most of the papers reported problems and were dealing with ways to improve mathematical skills of undergraduate students.

The main problem is that the teaching of chemistry is hampered by the lack of mathematical skills.

Students have to have a certain level of knowledge of mathematics before they come into the lecture. If they are not familiar with certain mathematical derivations you want to use in your lecture, students will not be able to follow the lecture. In physical chemistry, for example, you need to be familiar with imaginary numbers. But familiarity with integrals and derivatives is also a must. If you want to use Taylor polynomials in your chemistry lecture it is wise to have your students familiarize themselves with that theory. It is a good idea to refer your students to the relevant chapter in the calculus book your mathematics colleague is using for his calculus course. By providing the students with a mathematical problem they should be able to solve before coming to the lecture, you give them an idea of the level of knowledge they need. The implication is that courses like calculus should be taken prior to taking more advanced courses in chemistry. As an alternative you could provide tutorials in mathematics for those students who do not have the necessary skills.

3.4 Post-lecture activities

The lecture normally is used to introduce new concepts. These concepts are used to demonstrate how phenomena observed during research can be interpreted and can be predicted. Or in a more basic setting, what the scientific background is of distillation for example. Students need to exercise using the new concepts and have to learn to solve problems using these new concepts. They should be able to apply the new concepts in contexts they will encounter in their later work. Homework is an obvious choice. Indicating the exercises and problems they have to do can be done either through a study guide or online through the E-learning environment. The E-learning environment has the advantage that students can hand in their work on line. This will enable you to give feedback.

Other organized activities include tutorials, computer labs, labs and so on. These will be discussed below.

3.4.1 Tutorial

3.4.1.1 Introduction

There are differences between a seminar and a tutorial. In the Merriam-Webster dictionary, a seminar is defined as a meeting between a professor and a small group of students often at the master level, discussing research at a high level. This section is not about such meetings. This section deals more with a tutorial, even though that is defined as a meeting with single students.

The function of this type of meeting is to help guide the learning process of students at a more individual level. Group size can vary, but is normally between 15 and 25. It shouldn't be smaller and it shouldn't be much larger. You can use this type of meeting in courses where the total number of participants is significantly larger than 30.

Figure 3.5: Students working in a tutorial (source: Pixabay).

3.4.1.2 Goal of a tutorial

The goal of this type of meeting is to
- Help students internalize the science content discussed in the lecture
- Train students' problem-solving abilities
- Illustrate how the science content discussed in the lecture is used in research
- Introduce students to the type of questions they need to be able to answer to pass the course
- Get an idea how well the students understood the content of the lecture

This can be done by
- Guiding and coaching students working problems related to the science content discussed in the lecture
- Illustrating and exemplifying the science content of the lecture, clear any misunderstandings that students may have

The small scale of the group is needed to be able to cater to students' individual problems and questions.

3.4.1.3 Teaching Assistants

Teaching assistants (TAs) cost money. As a lecturer, you will need to check with the faculty board how many, if any, TAs you may involve in the course. As a lecturer, you should at least lead one tutorial yourself.

Depending on the group size attending the course, and of course the arrangements with the faculty, you either do the tutorials yourself or you involve TAs. You should not be coaching more than two tutorials. It is vital that you discuss the role TAs play in the tutorial. Very often they have had little educational training. Sometimes your institution will provide training for TAs (Gallardo-Williams & Petrovich, 2017). They need to know how to work with the group, but most importantly they need to be aware what you want them to achieve with the group of students. They need to get some pedagogical background about learning. They need to be made aware of optimal ways to help students learn. During a tutorial, they need to lead the group, give an introduction, explain what is expected of the students, present the agenda, coach the groups of students or individual students while working on the problems, lead the plenary discussion about the way the set problems can be solved and finally wrap up a session. Without training and experience this is not easy.

After the tutorial, TAs need to be able to report back to you about the progress of the students in the group they have worked with. It will give you the opportunity to gauge the level of your students and will give you information on things you may need to spend some extra time on during the next lecture.

One of the ways, you can get information about the tutorials, is by having a meeting with the TAs between the lecture and the tutorial. As the TAs are expected to be present at your lecture you can get direct feedback on your performance from them as well.

3.4.1.4 Agenda of a tutorial meeting

Together with the TAs you can set the agenda for the tutorial session. This involves both the work students should do before the tutorial and what they should do afterwards. A typical agenda of a tutorial meeting is given in Table 3.4.

The tutorial is not meant to make exercises used to familiarize the students with a formula for example. That is something they need to do before the tutorial.

Table 3.4: schedule for a tutorial.

Time (min)	TA activity	Student activity	Goal
Pre-tutorial		Making exercises	To become familiar with the type of problems to be solved
0–10	Introduction, answers questions interactively	Pose questions about lecture and exercises	
10–12	Introduction problem 1	Listen	Make sure students know what is expected
12–35	Coaching of groups	Work in groups on problem 1	Train problem-solving abilities
35–45	Discusses interactively problem-solving strategy for problem 1	Interact with TA	Assess level of students
45–60	Break	Break	
60–62	Introduction problem 2	Listen	Make sure students know what is expected
62–85	Coaches groups	Work on problem 2	Train problem-solving abilities
85–90	Discusses interactively problem-solving strategy for problem	Interact with TA	Assess level of students
90–92	Introduction problem 3	Listen	Make sure students know what is expected
92–110	Coach groups	Work on problem 3	Train problem-solving abilities
110–115	Discusses interactively problem-solving strategy for problem	Interact with TA	Assess level of students
115	Wrap up of tutorial	Hand in worked solutions	
After lecture	Mark worked solutions	Receive feedback on worked solutions	Assess level of students

Tutorials are meant for the type of problems students need to be able to solve in a final examination. More importantly, they have to become aware of how they can use this type of skill and knowledge in future research.

During the lecture, preceding the tutorial, you will have introduced several concepts you want the students to work with. Most likely they will need to use these concepts to solve a problem or to get more insight in a process they want to study. In the case of distillation mentioned earlier, that could be the calculation of the plate height. Setting them a problem the students need to solve will give them a better grasp of the concepts discussed in the lecture.

You need to choose the exercises as well as the problems together with the TAs. Make sure they understand what you want to achieve by giving the students a particular problem. Try to give them authentic problems. Authentic problems are real problems encountered in real-life situation. They may be simplified, so the students are able to solve them. During their research, where they will use the knowledge the students are acquiring, problems are often open ended. It will not be certain that a solution is correct. Problem solving is part of a larger process. This should become clear to students as well.

The level of the problems is an important issue. If they are too easy students will no longer be motivated to come to the tutorials. If they are too difficult they will get frustrated.

Students will not immediately be able to design a problem-solving strategy. They need to be trained to do so. A simple straightforward strategy that can be used to work any kind of problem is called the Systematic Problem-Solving Approach (Gok, 2015):

- It involves as a first step an analysis of the given variables, the relevant concepts and relationships, and the desired answers
- From this inventory, a strategy is designed to find the answer, using the given variables and the relevant theory. To construct the strategy, diagrams are often helpful to indicate relationships.
- Once the strategy is set, the answer is calculated or derived.
- Finally, a check is made to see if the answer is more or less logical.

If you want your students to adopt this approach you will need to demonstrate this approach explicitly every time when worked solutions to the problems are handed out or discussed with the students.

Finally, because students will normally work in a group when doing research, you can choose to let them work alone or in groups. When using the Systematic Problem-Solving Approach, it seems most logical to do the first two steps, as well as the last step together. The third step using the chosen strategy to work the problem is normally an individual process. Having students compare the results after they have done the derivation and calculation separately will also give some sort of indication about the accuracy of the solutions they have found.

3.4.1.5 Problems during the tutorial session

There are several possible issues that can occur during a tutorial. The first is attendance. You may make attendance a requirement of the course, but still the number of students attending the tutorial can drop. If that is the case with just one TA, he or she has a problem that needs to be solved. If it is the case for all tutorials most likely the students feel the tutorial has no added value. Either it is too easy or it is too difficult. If that is the case the remedy is obvious as well.

You can also get mixed reactions. Some students think the level is too high, others may find it too low. This is especially the case when the background of the students is different. Often courses are open for students from say engineering and science, or for pharmacy and chemistry. This difference in background can lead to that type of reactions. You can solve such a problem by grouping the students according to their background. The requirements of the course will not change, but it is easier to pay attention to specific problems students may have.

3.5 Use of laboratory

3.5.1 Introduction

Chemistry is a science in which lab work often plays a dominant role. Most sciences actually involve a lot of practical work. It seems logical therefore to include practical work in science education, especially in the undergraduate study.

Practical work can differ enormously. It may vary from synthesis and analysis of a compound, to measurements and analysis of data. Students need to learn using instruments for spectroscopy, Gas Chromatography Mass Spectroscopy (GCMS) to name a few. In chemistry, they need to learn to use the available glassware and follow lab procedures.

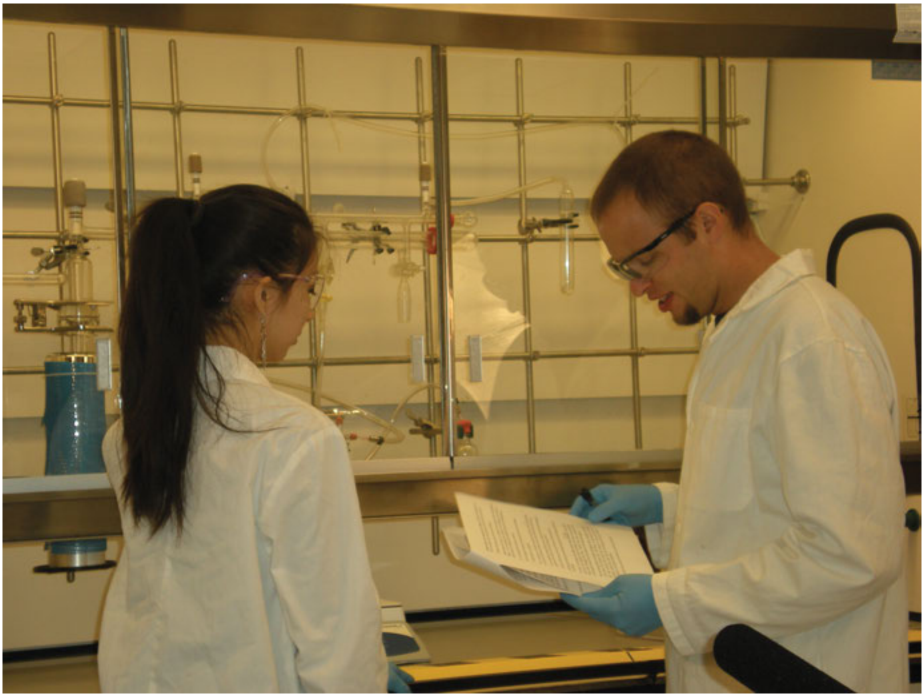


Figure 3.6: Working in a chemistry lab (source: Flickr).

3.5.2 Goals of practical work

For the use of practical work in education, several reasons can be formulated (Hofstein & Lunetta, 1982):

1. To arouse and maintain interest, attitude, satisfaction, open-mindedness and curiosity in science
2. To develop creative thinking and problem-solving ability
3. To promote aspects of scientific thinking and the scientific method (e.g. formulating hypotheses and making assumptions)
4. To develop conceptual understanding and intellectual ability
5. To develop practical abilities (e.g. designing and executing investigations, observations, recording data, and analysing and interpreting results)

Practical work offers a rich environment for learning. It needs careful planning in order to achieve these learning goals. Buck et al. (2008) have attempted to characterize practical work according to the goals it wants to achieve.

Table 3.5 lists an overview of the way inquiry in the undergraduate laboratory can be characterized.

Table 3.5: Characterization of level of inquiry in undergraduate laboratory (adapted from Buck et al. (2008).

Characteristic	Level 0: confirmation	Level ½: structured inquiry	Level 1: guided inquiry	Level 2: open inquiry	Level 3: authentic inquiry
Problem/question	Provided	Provided	Provided	Provided	Not provided
Theory/background	Provided	Provided	Provided	Provided	Not provided
Procedures/design	Provided	Provided	Provided	Not provided	Not provided
Result analysis	Provided	Provided	Not provided	Not provided	Not provided
Conclusions	Provided	Not provided	Not provided	Not provided	Not provided
More structure	◄	———	———	►	Less structure

Several levels have been introduced based on the activities that students are expected to do.

These activities are based on the way research is conducted at university. Ultimately one of the goals is to educate students in such a way that they can do independent research within a group.

These activities can include the following:

– Students need to be able to formulate a research question or a problem they need to solve
– Students need to be able to familiarize themselves with the theory and the background

- Students need to be able to formulate a hypothesis or an expectancy of what they will find
- Students need to be able to formulate a procedure or design of an experiment they are to perform
- Students need to be able to gather the data/perform the experiment
- Students need to be able to analyse the results of the data they have gathered
- Students need to be able to communicate the results
- Students need to be able to relate their results to existent literature
- Students need to be able to draw conclusions from the experiment

Depending on the activities students actually do in a lab session, a lab assignment can be characterized as (see Table 3.5)
- confirmation;
- structured inquiry;
- guided inquiry;
- open inquiry; and
- authentic inquiry.

When laboratory experiments were analysed according to Table 3.5, out of 386 experiments only 26 were considered "guided inquiry" and only 5 were "open inquiry", even though students at the end of their bachelor are expected to have mastered level 3. Table 3.5 gives an opportunity to analyse a laboratory assignment (Buck et al., 2008).

From these data, it can be concluded that in most undergraduate labs, students only gather data, report on the data and draw the conclusion that the theory is correct (level 0 and ½ from Table 3.5). Because students realize they are just repeating experiments, they are not stimulated overmuch and often do not prepare well for a lab period. They are not really aware of what they are doing and are not very interested. They don't see the learning effect of the lab, and therefore are not very motivated. It is a chore to get through. Making a practical assignment more challenging is one of the ways to achieve more student interest. Besides it prepares them better for future lab periods, which is as important as making clear what you want your students to achieve and learn in the laboratory assignment.

There are plenty of examples in which the design of a lab activity can be changed to accommodate more goals. One example is a lab activity at the University of Chicago (Keller & Kendall, 2017). In the honors class of an organic synthesis lab the procedures were changed in such a way that the students were involved in a lot more activities than they were in the regular class.

They were expected to (Keller & Kendall, 2017):
- Search for and obtain literature articles
- Evaluate the literature for relevance
- Prepare an experiment based on published results

– Work within a group to accomplish a common goal
– Present results in a professional manner

This included deciding themselves which spectroscopic method was needed to determine the result of steps in the synthesis and deciding whether their intermediate was pure enough to continue with the next step.

It is not that difficult to adjust a lab exercise which contains more activity from the students. Consider the following example:

Most general chemistry courses introduce simple titration labs. Very often the complete procedures for this type of lab exercise are given. All the students have to do is to follow the exact steps given. Changing this procedure slightly gives students a lot more insight in the whole process. For titration, students need to familiarize themselves with the use of the volumetric glassware. This can be done in a regular lab session of maybe 3 hours, in which volumetric glassware is introduced. They need to practice at least with a pipette, a burette and a volumetric flask, apart from regular glassware such as beakers and Erlenmeyer flasks. They should also practice with a simple HCl/NaOH titration, so they are also familiar with procedures and observing an endpoint.

Assuming that in the theoretical lectures they have learned about endpoint pH, and calculations, you can then give them the assignment to bring vinegar into the lab for the next session and to determine the acetic acid concentration in the vinegar. They should write a work plan to do so themselves. After they have determined the concentration, have the group compare their results. Indicate that the results should not vary more than 1%. Then have the students discuss what could be improved in their procedure. Have them redo the experiment the next time, ensuring this time that results are within 1% of each other.

When you plan a lab session it is important to formulate the exact goals you wish to achieve. As mentioned above these goals may involve:
– Development of practical abilities
– Arouse interest, attitude, satisfaction, open-mindedness and curiosity
– Develop conceptual understanding and intellectual ability
– Promote aspects of scientific thinking and the scientific methodology
– Stimulate creative thinking and problem-solving ability

Equally important is that the students are aware of the learning goals you wish to achieve.

3.5.3 Actual planning of a practical activity

There are several bottlenecks for practical work:
– The number of laboratories
– The facilities like hoods, gas, electricity, air, vacuum in the rooms

- The glassware that can be used
- The measuring instruments available
- Computers and Information and Commuication Technology (ICT) available
- The number of lab assistants you may use
- Safety procedures in the lab

If you plan a lab activity you are the ultimate person responsible for the safety of the students and lab assistants working during the activity. That should be your first concern.

One of the factors in safety is the number of students per lab assistant. Even though this depends a bit on the type of activity of course, that should not be above 8 to 10.

Instruction about lab safety is an important factor in safety in the laboratory. Students should be very aware of safety measures. Not only self-protection measures like goggles, gloves and lab coat that should be used, but especially procedures in case of an emergency such as where to go, who should be notified and so on but also specifically what not to do and leave to others. Safety instruction should include the possibility that the TA responsible for the group is himself or herself incapacitated. Special precautions in the lab, like the use of a hood, not eating and drinking in the lab must be enforced. Special care must be taken for measures to prevent pollution of the environment, when disposing of waste materials, including chemicals, solutions and broken glassware.

You will need to prepare some sort of written instruction for the students.

3.5.4 Preparation

When planning the lab take into consideration what a student should do before he/she comes into the laboratory. Planning lab work is something students should learn. Part of planning should exist for familiarizing the students with the way the lab works; for example, learning where to find materials, how to obtain a spectrum, where to get the equipment to be used during the lab, how to set up and use the glassware, the measuring instruments and so on during the experiment. Students should by that time also be familiar with safety procedures. This will help them in formulating their work plan.

Part of the formative assessment of this part of a lab period could be a short video made by the student in which he or she demonstrates that he/she is able to use the glassware or instruments as they are supposed to be used. There are many examples, but include the ones like the use of a burette, a pipette or the use and safety in working under vacuum. Almost everyone has a mobile phone that can be used for making such a video.

By making this a prerequisite for the actual experiments you want them to perform you stimulate the students to pay much more attention to this part. It will enhance the results of the actual experiments.

There should be a sufficient time lap between this introductory part of the lab and the actual experiment you want the students to perform. They need to think about what they learned, so they can actually use their experience in their proposed work plan.

Students should formulate a work plan before they start their lab work. Such a work plan should include some remarks about lab safety.

A work plan can also include some preliminary experiments students might want to perform before they can finalize their work plan.

In the work plan some of the goals you wish to achieve with the practical activity can be assessed. Important aspects like

– students need to be able to familiarize themselves with the theory and the background;
– students need to be able to formulate a research question or a problem they need to solve;
– students need to be able to formulate a hypothesis or an expectancy of what they will find; and
– students need to be able to formulate a procedure or design of an experiment they are to perform

can be assessed in the work plan.

Have the students come in before the day the lab is planned and let them check their lab work plan with a TA. Or you can have them submit it in electronically. They should get feedback and not be able to start their work without formal clearance by you or the TA.

This type of preparation gives you and the people assisting in the lab session enough time to assemble all the instrumentation and glassware needed for the actual experiments. One of the most often heard comments is that staff has no control over the experiments when they are planned so open. Giving enough time for assembling the material will show that this is not a real problem.

3.5.5 Performing the experiment

Plan enough time for students to perform the experiment. If you want to assess their practical abilities during the experiment, make sure you have an adequate protocol both for the assessor and the assessed students. They should be made aware what they are being assessed on, especially if it is a type of summative assessment.

Make sure the students gather enough and accurate data, and stimulate them to take photographs or sketches of their set-up.

3.5.6 Reporting

Reports are needed to assess the following goals:
- Students need to be able to analyse the results of the data they have gathered
- Students need to be able to communicate the results
- Students need to be able to relate their results to existent literature
- Students need to be able to draw conclusions from the experiment

Requirements for the report should be formulated in such a way that the relevant learning goals can be assessed.

Reports can be made in several ways. You may require a written report, following a certain format. Several possibilities exist. In early courses, pre-printed formats are often used. In later courses, the format of articles may be used.

In order to exchange information between students, posters or PowerPoint presentations can also play a role. Basically, students need to learn how scientific results are communicated. Posters, oral presentations and articles are the predominant form in which this happens. It seems logical to use these in the training phase as well.

3.5.7 Affective domain

The lab work is often seen as one of the attractive aspects of studying science and chemistry in particular. It gives some insight in the type of work the students will be doing in later stages.
These goals in the affective domain stimulating
- interest,
- attitude,
- curiosity and
- open-mindedness

are often not explicitly formulated. In the assessments described, affective goals are not measured. It is important for the design of the whole lab activity to do this however. You can make this part of the evaluation of the whole lab activity.

There are several ways to assess these goals and to evaluate. You can use a questionnaire that is presented to the students, or you can interview some of them in which you query them on these aspects. This could also be done when you or the TAs discuss a student's report with a student after it has been graded.

3.5.8 Evaluation

As all educational activities, you should evaluate this particular activity as well. Based on the work plan and the reports you can get some indication whether you reached the learning goals. A discussion with the TAs is part of the evaluation. For yourself as well as for the TAs it is important that the students rate them. This can be part of the questionnaire used to assess the affective domain.

3.6 Mentoring group work

3.6.1 Introduction

There are several types of groups that you may be asked to mentor. First year students often have problems adapting to the change between secondary school and university (Chaplin, 2007). In other cases, you may be asked to guide students engaging in some group assignment. Students need to learn how to work and function in a group. During their professional career, they will normally be part of a team, with their own responsibilities. They need to learn how to function in a group. Apart from that, skills training and cognitive training will also be part of the group work.

3.6.2 Role

The role you have in leading group work is that you are more a coach than a teacher. Instead of being a source of information you are now there to guide the process going on in the group. Basically, your role is the same as a sports coach. The subject is different, however. You are not focusing on athletic abilities and skills, but on learning skills. Your main goal is to improve the learning skills of the students by showing them how to gather information, how to process the information directed to the assignment the group has to fulfil.

When you are coaching a first-year group, focus will be on general study skills such as critical reading, time management and self-directed learning. You will be amazed how much difficulty some students may have in adapting from high school to college (Chaplin, 2007). Helping the students "how to learn" is the main focus of these groups. They often have poor time management, are not very skilled in note taking and don't listen very well. Very often some guidance will help them on their way and adapt to this new situation.

3.6.3 Supervision groups

There are several aspects you need to be aware of in supervision of students.

You need to be aware of the task you have regarding a group of students. You act as coach, teacher, critic and judge. You also have a task in the summative assessment of the student. This double role can create some problems. You will need to decide how you build up a relationship with the students.

- Will you keep it business like or personal?
- Do they address you as professor, or do they use your first name?
- How intensive is your supervision? Will it be very close, students need to report to you in short time intervals, or is it distant, students report only after major steps have been taken?
- What is the orientation of your supervision? Is it product oriented or is it focused on the process?
- How well prepared are the students? How are their writing skills for example?
- How can students be coached into a certain direction?
- What do you expect from your students?
- What are you responsible for?

Answering these questions and discussing them beforehand with the group of students will make your role as a supervisor much more easy and effective.

3.6.4 Approaches

As a coach in such groups you can choose different approaches depending on the ability of the group (Glickman & Gordon, n.d.):

- You can take a nondirective approach, when the students are clearly able to find their own way and take initiative. The students collaborate and have equal input.
- An informal directive approach for groups who have problems finding a way to cope and start with their assignment. You can provide them with several options from which they choose one. After that the students collaborate.
- A directive approach for students at a lower level, where you take the responsibility for the type of action to be taken. You divide tasks and make sure everybody has enough input.

3.6.5 Feedback

Normally the group work will be part of a course in which you have the role of mentor/coach of the group. You will be asked to give feedback to the results of the group work regularly.

There are several types of feedback that can be asked as is indicated in Table 3.6. There are different types of comment, as is indicated in Table 3.7.

Both for the feedback you receive and the feedback you give to students these indications are important. The types are easily recognizable. The type of feedback you give depends on the phase of the work. There are three phases in group work:

Table 3.6: Types of feedback askers.

Type	Strategy
Applause claimer	Only wants compliments and is not open for negative feedback
The sceptic	Does not believe positive feedback and keeps on polishing up the text
The conformist	Adapts to all comments. Takes over each suggestion immediately
The perfectionist	Only wants feedback in detail, and not open for big fundamental changes
The defender	Tries to refute all criticisms directly and is not really interested in feedback

Table 3.7: Types of feedback givers.

Types	Advantages	Disadvantages
The cheerleader	Positive for your ego	No criticism, little feedback
The pedant	Indicates all small mistakes	Does not look at higher text levels
The sloganist	Clear opinion	No argumentation
The rewriter	Good suggestions	Unasked interferences
The grumbler	Very critical on small mistakes, inaccuracies, inconsistencies	Nothing positive
The cop	Knows all rules and conventions	Does not appreciate unconventional things
The co-thinker	Very dedicated	Takes over your text

- Starting phase
- Working phase
- Final phase

Identifying these will help you in finding the right type of feedback which is needed and makes it more effective.

3.6.6 Feedback on your role as supervisor

For your own development as a coach it is important that you receive feedback on your role as mentor of a group. The best way to do is to ask for feedback at the end of the group work in one of the last meetings of the group.

3.7 Supervising (un)graduate students

Working with graduate students is actually one of the oldest ways of teaching going back to the guilds. The main difference is that here you function as a teacher in a one-to-one relation, more in a master-apprenticeship situation. There will be courses in your institution in which you will be familiarized with your role as supervisor. It is advisable to take one of these.

Most universities will have regulations in place regarding the supervision of graduate students. Very often it will entail the signing of a contract between you and the student, in which both your role and that of the student are discussed and formulated.

Part of the regulation will be the formal meetings in which progress and go/no go moments are laid down.

As a teacher and supervisor, you need to make sure the student develops into an independent researcher. As he or she is part of your research group the role you play is rather complex and has different facets. Most important is that there is a positive relationship between you and the student. The student must be able to rely on you to help and guide him or her, especially in the beginning. In later stages, you will slowly withdraw your help and discussions will be held on a more equal basis.

3.7.1 Reports by students

In the course of their work students will report regularly within the scope of the work within your research group. There will also be more formal discussions with the student. Sometimes you will have these alone with your student, and sometimes others will be present as well.

It is wise to structure these talks beforehand, so it is clear

- what will be discussed exactly;
- what the goal of the talk will be;
- how far it will be confidential;
- who will make a report, and for what purpose the report will be used; and
- maximal duration of the talk.

There are several types of meetings you can have with students:

- orientation talk;
- report of achievements;
- performance appraisal;
- go/no go discussions;
- corrective discussion; and
- bad news discussion.

Normally there are several steps to be taken.

- Introduction:
  - identify everybody present, including the role they have;
  - identify the goal of the conversation;
  - identify what the result may be; and
  - identify who will compose a report of the meeting.

- The actual discussion, in which you act as chair, giving the floor to speakers
- Concluding the talk:
  - give a short summary of the main points raised;
  - give a short summary of the conclusions reached; and
  - indicate what the follow-up of the discussion will be.

3.7.2 Feedback

For your own development as a supervisor it is important to regularly ask for feedback. Make sure you have an exit interview with each student who leaves, especially when he or she does not graduate.

4 Assessment in a chemistry course

4.1 Types of assessment

Assessment is a broad term encompassing different fields. According to the online version of Merriam-Webster, it means “the action… of making a judgement about something”.

In education two types of assessment are distinguished. They are called formative assessment and summative assessment (Offerdahl & Tomanek, 2011). Formative assessment has a goal to determine the level attained by a student either in the cognitive, psycho-motoric or affective domain (Bloom, 1984). Within the cognitive domain both knowledge and skills may be tested. In the psycho-motoric domain most often practical skills are meant. The assessment is important for both the teacher and the student. For both, the information is vital for further actions in the learning and teaching process.

Diagnostic assessment is a specific type of formative assessment often used at the beginning of a course and used to “diagnose” the level of expertise of a student, and to find out whether the student can enter a particular course.

The other type of assessment is called summative assessment. Summative assessment has as its main goal to mark or score students. It is not only used to determine whether a student has acquired sufficient proficiency in a certain field, but is also used to rank the students among each other. Summative assessment often coincides with formative assessment. For summative assessment, however, certain regulations are often applied by institutions, while formative assessment can normally be used without restrictions.

4.2 Criteria for assessment

In 2002, the Assessment Reform Group (https://assessmentreformgroup.wordpress.com/publications/) published a number of pamphlets and leaflets about assessment. The group stresses the importance of assessment and the role it plays in education. Specifically, in “beyond the black box” the group indicates that learning through assessment depends on five key factors:

- The provision of providing feedback to students
- The active involvement of students in their own learning
- Modifying teaching to take into account the results of assessment
- A recognition of the influence assessment has on motivation
- The need for students to be able to assess themselves

These factors are an important background for the need and the design of assessment.

https://doi.org/10.1515/9783110569582-004

In the leaflet, "Assessment for learning: 10 principles" (Broadfoot et al., 2012), 10 principles are published:

Assessment for learning

1. is part of effective planning;
2. focuses on how students learn;
3. is central to classroom practice;
4. is a key professional skill;
5. has an emotional impact;
6. affects learner motivation;
7. promotes commitment to learning goals and assessment criteria;
8. helps learners know how to improve;
9. encourages self-assessment; and
10. recognizes all achievements.

These principles are all valid and used in the design of assessment.

4.3 Formative assessment

4.3.1 Introduction

Formative assessment has been shown to improve learning significantly (Black & Wiliam, 1998). From another article (Smith, 2007) it becomes clear that the formative assessment has to be in line with the learning objectives of a course, otherwise it will not have any effect. The formative assessment activities need to be focused on helping the learning process of the students. Formative assessment should show the student what he/she knows and what he/she doesn't know. The results should have an effect on both the students and the teacher. For the students, it should direct them to their weak points and stimulate them to work on those. Teaching assistants (TAs) and lecturers should be able to give individual feedback on the learning process and help individual students improve. For the teacher, it will yield information on aspects that need to be discussed during lectures and tutorials, because some of the concepts have not been understood well enough. Some of the issues are better addressed in the whole class, and others can be easily addressed in the smaller scale of a tutorial.

The main criteria of formative assessment are that

- it activates the students;
- it stimulates students;
- it challenges students;
- it demonstrates the students' proficiency; and
- it guides students in their learning process.

4.3.2 Techniques of formative assessment

In Chapter 3, several ways of formative assessment have been discussed. During lectures "nearpod" was introduced as a technology tool. An important issue in formative assessment is that it can stimulate the discussion students can have among each other. Discussing answers to questions about concepts helps enormously for a deeper understanding. Mazur (1997) demonstrated that clearly. After the initial answers that students gave on a Mazur-type question, they discuss and explain their answers. In the second time of answering the number of correct answers often increases significantly (Barth-Cohen et al., 2016).

The main idea for stimulating discussion among students comes from Vygotsky (1978). As indicated earlier, students may help each other in obtaining a higher level within their zone of proximal development. Discussion about concepts and answers helps students revise their opinion and insight in questions. It helps them understand a concept and its implications a lot better.

Collaborative assignments during a tutorial are also a way to induce communication about solving problems. It helps engage students, and lets them build on each other ideas (Siegel, Roberts, Freyermuth, Witzig, & Izci, 2015).

Using online assessment, where students hand in worked solutions or answers to problems, is just one of the ways in which it is possible to give feedback online. In Chapter 3 in the description of the tutorial some attention was given to this type of activity.

4.4 Summative assessment

4.4.1 Criteria for summative assessment

There are several criteria that should be applied to summative assessment:
- The assessment should be valid
- The assessment should be reliable
- The assessment should be transparent
- The assessment should be efficient

These are criteria that normally are also held for research.

Validity means that there is a relation between the assessment and the learning objectives you have set in the course. It also means that the assessment is able to discern the difference in level of the students. Cum laude students should score a higher grade than average students. Students that have not achieved your learning objectives should not receive a passing score.

Reliability means that this particular assessment gives consistent results every time it is used. That means that the results of the assessments should be comparable to earlier assessments.

Transparency means that the students need to be aware of what is required of them in order to succeed in the assessment. They should know what they are expected to do. That means there should be no ambiguity about what students are supposed to answer. There are several examples of ambiguous questions and answers.

Consider, for example, the question:

Where was the declaration of independence signed?

Answer: *At the bottom of the page (answer a gifted child would give)*

And also the answer in Figure 4.1, found on the Internet.

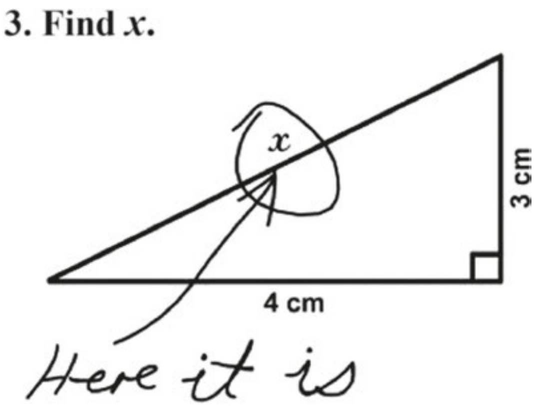


Figure 4.1: Answer to a question.

Transparency also means that students are aware of the assessment criteria.

The effectiveness relates to the way an assessment is fast and efficient not only in reaching its goal but also in its contribution to the learning process of students.

4.4.2 Levels of knowledge

One of the main goals of assessment in general is to determine whether you reached your learning objectives. In summative assessment, the main goal is to assess the level of knowledge of (individual) students. One of the first things you need to know is how you might define the level of knowledge. Bloom (1984) was one of the first to define a taxonomy of learning, where he defined levels of knowledge in three domains: the cognitive, the psycho-motoric and the affective.

Table 4.1 explains these levels, by using verbs, describing activities that students can demonstrate (Bybee, Powell, & Towbridge, 2007).

Table 4.1: Levels in Bloom's taxonomy.

Domain	Low level					High level
Cognitive	Knowing	Comprehending	Applying	Analysing	Evaluating	Creating
Affective	Receiving	Responding	Valuing	Organizing	Characterizing	
Psycho-motoric	Simple	Imitation	Manipulation	Precision	Articulation	Naturalization

The three domains have been described in detail, differentiating into general objectives and behavioural objectives using verbs to describe students' actions related to the particular level.

The cognitive domain is characterized by knowledge. It starts with simple knowledge, and advances in steps to more and more complex levels. The more cross-links are formed, the more knowledge is chunked, and so the higher the level of knowledge, the more an individual becomes an expert. However, it takes time and a lot of conscious effort to reach that level.

The affective domain has been neglected for quite some time, leading to severe problems in secondary education (Rocard et al., 2007). The affective domain deals with emotions, feelings and attitudes of students. It is not easy to formulate goals for the affective domain, and even more difficult to formulate assessment to measure progress in the affective domain. Very often this is also linked to the lecturer, not as much the content of the course itself. Still it is an important aspect for higher education. Lectures and courses are the only way to introduce students to research in your own field. You need enough students to be able to help your own research group prosper.

The psycho-motoric domain deals with physical manipulations, the handling of glassware, laboratory equipment and so on. This is not the only part of a course, interpretation of what is observed and reacting to that is an important part as well. Diagnosing of what can be improved in a certain set-up, for example, is a higher level in the psycho-motoric domain.

When you think of dissecting, for example, it means recognizing patterns and structures in the object being dissected. This takes time to learn. The same is true for microscopic work.

Learning to handle the microscope is one, but finding and identifying specific items is also part of this domain.

Several of the verb lists, describing actions in a specific domain, can be found on the Internet, using Google. Some of the examples are given in Table 4.2.

These verbs and related verbs can be used to define learning objectives at different levels. It is not always easy to differentiate between two levels. Because of that these levels are often adapted fairly. Another factor is that the number of levels is high. It is not always needed to differentiate so many levels, so often the number of levels is reduced to four.

Table 4.2: Verbs relating to Bloom's taxonomy levels.

Cognitive domain		Affective domain		Psycho-motoric domain	
Level	**Verbs**	**Level**	**Verbs**	**Level**	**Verbs**
Knowing	Define State Recall List	Receiving	Attend Ask Differentiate Accept	Simple	Observe Analyse Accept
Comprehending	Describe Interpret Compare Relate	Responding	Comply Volunteer Engage in Recite	Imitation	Copy Execute Follow
Applying	Solve Discover Select	Valuing	Support Argue Initiative	Manipulation	Re-create Perform Implement
Analysing	Infer Contrast Discriminate	Organizing	Adhere Defend Explain	Precision	Demonstrate Show Calibrate
Evaluating	Reframe Devise Organize	Characterizing	Act Propose Revise	Articulation	Combine Coordinate Modify
Creating	Construct Develop Rewrite			Naturalization	Design Manage Invent

In further research the group of Bloom combined some aspects of knowledge in the cognitive domain, in order to include actions that can be taken related to knowledge (Anderson & Krathwohl, 2001). The cognitive domain is divided into two different dimensions, each looking at different aspects of knowledge. In their paper, they called it the knowledge dimension and the cognitive process dimension. In both directions, different levels can be discerned.

The knowledge dimension is:
- Factual, the basic elements students must know in order to understand a discipline
- Conceptual, the interrelationships among these basic elements, combining into a larger structure
- Procedural, how to do things, methods to work within the structure, using skills, methods of research and so on
- Metacognitive, awareness about the way related knowledge may be acquired, interpreting research results

The cognitive process dimension is:
- Remember, retrieve knowledge from the long-term memory
- Understand, construct meaning from instruction

– Apply, carry out procedures in a given situation and solve problems
– Analyse, break up a problem in its constituent parts, analyse the structure and apply the right methodology
– Evaluate, use results to draw conclusions
– Create, put different elements together, to form a coherent system

Understanding these different levels is important in formulating your learning objectives, as well as designing the summative assessment. It is clear of course that within a field you start at the factual knowledge and work your way up to higher levels.

4.4.3 Use of knowledge levels in summative assessment

Using the knowledge dimensions discussed earlier in summative assessment presents an opportunity to analyse your summative assessment, before you use it on students. In international studies such as Trends in International Mathematics and Science Study (TIMSS) (Mullis & Martin, 2015), three levels of knowledge are used:
– knowing;
– applying; and
– reasoning.

In some cases, these levels are subdivided into more levels (Bertona et al., 2014). Most often the apply level is divided into two levels:
– apply in a known situation and
– apply in an unknown situation.

This yields four levels at which students can be assessed.

The lowest level, knowing, is easily defined and is focused on recall of factual information. Multiple choice exams are perfect for assessing this type of knowledge, even though it focusses on recognizing terms and definitions. It is not a very active form of assessment.

The second level is the level in which procedural knowledge is assessed in simple situations. Normally the student is asked to apply this knowledge in a known situation.

In the third level, the student is asked to apply procedural knowledge, in which he/she uses conceptual knowledge in order to solve a problem in a situation he/she is not familiar with.

In the fourth level, he/she is asked to analyse a given problem in order to apply the knowledge he/she has acquired. From the analysis, he/she is able to solve the problem.

A simple example of the levels involved would be the following, which is taken from an organic chemistry course at the University of Groningen (see figure 4.2).

Level 1, recall:
Which of the following compounds is aromatic?

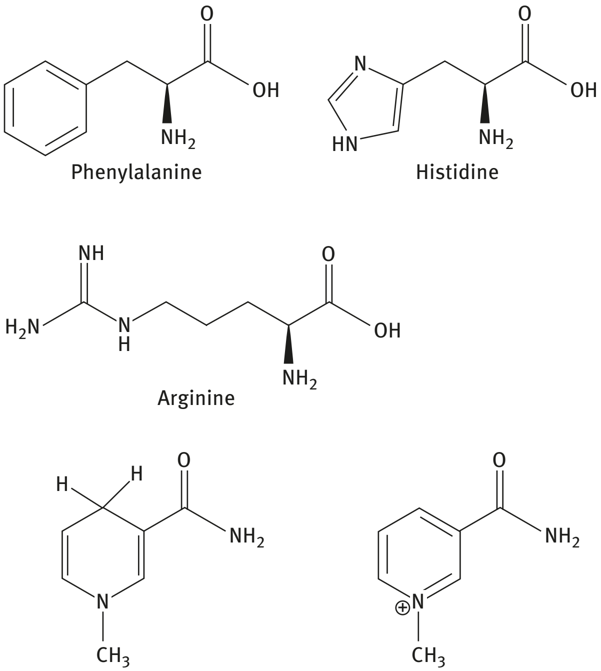


Figure 4.2: Part of assessment question.

Level 2, application simple:
Nitronium (NO_2^+) ions may react with tyrosine present in a protein chain. Give the reaction mechanism and explain where the NO_2 group will bond.

Level 4, analyse:
Explain why tyrosine reacts more easily with nitronium ions than phenylalanine.

Using these levels, you can use a so-called test matrix in order to analyse the summative assessment you are using. Table 4.3 gives an example of such a test matrix. The test matrix is based on a final exam containing questions/problems. It is an easy way of determining the level of your exam, before you use it. It will also link the exam to your learning objectives. Determining the levels of your questions will also give an indication of the difficulty of the exam.

In the bottom row, you get an indication how the final score of a test is determined. This way you can set the minimum score for a passing mark on the exam.

You may set expectations for your students: a normal score would be
- 100% on recall;
- 75% on level 2;

Table 4.3: An example of a test matrix.

Test matrix							
	Cognitive skills				Other skills		
Learning goal/ objective	Level 1: recall	Level 2: apply easy	Level 3: apply difficult	Level 4: analyse	Affective	Psycho-motoric	Number of points in test
Percentage in test:							

– 50% on level 3; and
– 25% on level 4 questions.

That will give you a minimum number of points students are expected to score.

You can also determine the difficulty level of your exams. An exam that has mainly questions in levels 3 and 4 will be considered more difficult than an exam with mainly questions in levels 1 and 2. A normal distribution would be:
– recall 20%;
– apply in known situation 30%;
– apply in unknown situation 30%; and
– analyse 20%.

You can vary these percentages of a course, depending on the type of a course. An introductory course might have a distribution as mentioned above. A regular student would score 62.5% on such a test. A more advanced course will have higher percentages in levels 3 and 4. Scoring your exams like this will give you an opportunity to discern the level of the students, as the better students will score higher on level 3 and 4 questions.

4.4.4 Designing summative tests

There are many ways of assessing students. For science, the most traditional way is a written exam, containing a number of problems that have been practiced during the tutorials. Most of the exams in introductory chemistry, be it general, physical, organic or inorganic, are set up this way. But writing a review of a number of articles giving a presentation about a concrete subject, making a poster about practical research, writing reports or articles are all valid forms of assessment. Even building an exhibit for a science exhibition can be used as assessment (Huisman, Bakker, van der Pal, de Jonge, & van der Wal, 2011).

The link to the learning objectives you want to accomplish are the key in determining the type of assessment. Portfolios may be used to assemble the different parts of the summative assessment.

Starting with the main general learning goals of the course is a good strategy. Use these learning goals as themes for the different parts of your exam. Ask your TAs for proposals for tasks and problems that can be used in the exam. Consult prior exams for guidance about the length of the exam. Test the exams by asking colleagues and PhD students to write the exam and use their feedback to adjust the problems.

The time needed to write the exams by students is at least double that of a colleague or PhD student.

The design of an exam is more than just writing up the questions. You will need to use a test matrix in order to justify the exam at a later stage. Another thing you need is a marking scheme.

4.4.5 Marking the exams

4.4.5.1 Rubrics

Marking an exam depends again on the type of exam. An easy way to score reviews, posters, presentation, articles, reports, exhibits and so on is the use of rubrics. A rubric is a table containing in the first column criteria that are important in the assignment. In the other columns, a short description is given about what is expected, including a possible score in the top row. An example of a rubric for a lab report is given in Table 4.4.

The website rubistar.4teachers.org is very helpful in writing rubrics for the first time. Normally it takes scoring of at least one assignment to improve a rubric. The experience of seeing what students do and what types of mistakes they make are helpful in designing a rubric.

For posters, criteria such as

- graphics;
- title;
- content;
- attractiveness; and
- accuracy

can be used. Emphasis on certain criteria can be used to determine a final grade. A requirement may be that one particular criterion must be scored at least sufficient for a passing score. In Table 4.4, that might be “science content”. Another requirement might be that no criterion may be scored insufficient. Normally the average score on the criteria is used to determine the mark for a particular student.

Table 4.4: (Partial)rubric for a lab report (see also rubistar.4teachers.org).

Criteria	Excellent (A)	Good (B)	Sufficient (C/D)	Not sufficient (F)
Components of the report	All elements are present and additional elements that were felt needed	All required elements were present	One element was missing	Several elements were missing
Diagrams/ graphs	Clear graphs and diagrams are used when needed, and labelled neatly and correctly throughout	Requested graphs and diagrams were used and labelled correctly	Graphs used were labelled incorrectly or some labelling was missing	Requested diagrams and graphs are missing and/or labelled incorrectly
Scientific concepts			Methods	Concepts not or incompletely understood
Methods	Methods are described completely, including all details	Methods are described completely	Methods are described, some aspects are missing	Incomplete description of methods used
....				

Rubrics are normally adjusted during use, to make them easier to work with. Rubrics are especially needed if more than one person is marking reports. Rubrics are a help for students as well. It shows them in a very clear way the conditions needed for a passing grade.

4.4.5.2 Written exams

When you have finalized the exam the first thing to do is make a marking scheme, to assign points that can be scored on the different items of the test. Sometimes this is easy. In the example given earlier about an organic chemistry test, the answer to the first question should involve three compounds. The other two are not aromatic. There are several ways to score the answers. The question was: “Which of the following compounds is aromatic?” In a correct answer, the first, second and fifth compounds are marked. This could lead to 3 or 6 points, 1 or 2 points for each correctly identified compound. Now what do you do if the third or fourth compound is also indicated as being aromatic. You will need to deduct points for the incorrect answer. Also leaving one of the aromatic compounds out would be incorrect. If you deduct 2 points for each incorrect answer, a student may have two compounds correct and still receive no points, while a student who has no idea, but labels all 5 as aromatic would receive 2 points. The conclusion is that you need to be complete in your marking scheme, including all possible answers. While marking the exam you may note possible answers that had not occurred to you but did occur to the students. You can of course include these in your marking scheme on the fly.

The second question was: “Nitronium (NO_2^+) ions may react with tyrosine present in a protein chain. Give the reaction mechanism and explain where the NO_2 group will bond.”

The answer involves a two-step mechanism, with several possibilities for mistakes, but this mechanism was discussed during the lecture with phenol.

The third one: “Explain why tyrosine reacts more easily with nitronium ions than phenylalanine.”

Here students need to analyse the structure and realize that in phenylalanine the resonance structures are different than in phenol.

The number of points could be about the same as for the first question, six for each question.

Supposing you have 11 of these comparable items in the whole exam you would end up with a total score of 66 points. There is no need to have a number of points like 50 or 100, although that is done often.

In order to determine the score for a student you need to decide the cut-off point for a passing score. That does not need to be 33 points or 50%. It may be higher or lower. Most people make list or histogram of the scores first before deciding.

Scores are depicted in Figure 4.3.

In the top graph, the group of 10 students scoring 60 points out of 66 is the group of excellent students; the group of 40 scoring 52 points out of 66 would be the group of average to good students; the group of 10 scoring 33 out of 66 the hard working but not very talented students; and the group of 40 scoring 12 out of 66 has decided not to prepare for the test. This would have been a group in which many students (40 out of 100) lost track during the course and felt they were not able to do well in the course.

Determining the mark for a student here depends on the type of scores used. In the United States, the marks would most likely be A for the first 10, B for the next 40, C or D for the group around 33 points and F for the lowest scoring students. If you need a decimal mark a formula like

$$\text{score} = \frac{\#\ \text{points}}{66} \times 10 + 1$$

would be possible if you mark between 1 and 10. This is used in a lot of countries. You can of course also use just the percentage score, marking between 0 and 10. This system is not used very often, because that would mean the group scoring around 33 points would not get a passing score.

4.4.5.3 Pitfalls in marking exams

When marking exams there are a few simple rules you should take. You have to be careful in scoring a test to avoid pitfalls that often happen, even though you are not aware of them.

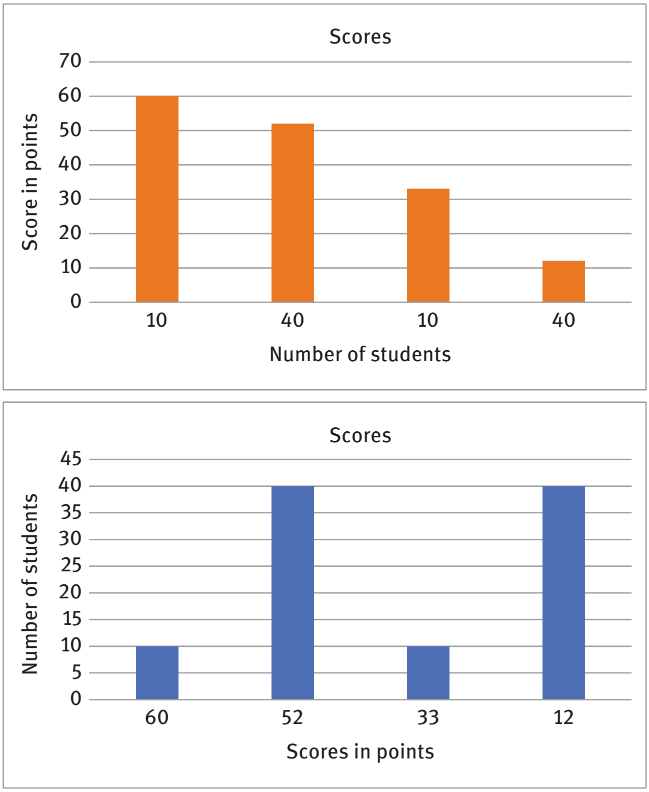


Figure 4.3: Distribution of average scores on a test (fictitious).

These effects during marking are:

- Signific effect means there is the change of focus in marking. Some mistakes are emphasized more during marking. This is opposite to a norm shift.
- Norm shift means you adjust the norm after you have seen a number of similar mistakes and become more lenient.
- Sequential effect is the effect that after a mediocre answer a better answer is marked higher than it would otherwise be.
- Contamination effect means you take into account who it is that answers.
- Halo-effect means you take into account the way an answer is written down, either sloppy or very neatly.
- Restriction of range usually occurs with rating lab reports or other types of exams; it means not the full score range is applied but only scores are given between 4 and 8. Scores lower than 4 are not given, but also none higher than 8 (often with the argument that 9 is for the teacher and 10 is for God).

Being aware of these effects helps in avoiding them. A few simple guidelines can be followed to avoid the effects as well:
- Mark a test question by question. That makes sure you will rate mistakes the same way for each student.
- Make sure you rate the problems anonymously. Shuffling the pile after each question will help.
- If you change the norm during the marking process, make sure you apply that to all students.

If you have used TAs for tutorials you should also allow them a role in marking the final exams. They can play a role in setting the exam but also in grading the exam.

When using several TAs it is absolutely vital that the TAs mark in the same way. The score of a student should not depend on who is marking them. One of the ways to ensure that is to have the TAs score one test independently and compare scores afterwards. The scores given by you and the TAs should be within 85% of each other. Discussing the differences with the TAs and deciding on the way an answer should be scored will raise this so-called interrater reliability.

One of the things you can do is to check some of the exams especially some of the high scoring students as well as students that score just around the passing score. This will also give you more insight in the quality of your exam.

5 Evaluation

After marking and determining the final scores for your students, your task is not yet finished. You will need to evaluate the course and write an improvement plan for the next time you teach the course. Many lecturers leave this unattended till about 2 weeks before the course is due to run again. Most people will have forgotten what exactly needed to be improved. The result is a course in which the same problems occur as the previous time.

5.1 Moments of evaluation

While the course is running, your evaluation should also start. A scheme should be set up for the evaluation of all activities, lectures, tutorials labs and so on. This will give the opportunity to adapt during the course.

Evaluating a lecture can be done by yourself, by taking notes about activities that went well, and activities that could have gone better. The TAs may also comment on the lecture. An external source is always better for feedback. Asking two or three students to give you feedback on a lecture, directly after the lecture, is a good idea. By sitting down with them for 10–15 minutes directly after a lecture will give insight into what they learned and what they experienced. Obvious questions for these students are:

- What were the main items you learned about today?
- Was the level too high/ too low?
- Could you follow the connecting thread of the lecture?
- What went well during the lecture?
- What could have been improved?

For tutorials, the TAs should take similar actions. In any case they should note concepts that were still unclear. For their own functioning as tutor, obvious questions are:

- Were the problems too easy/ too difficult?
- What could be improved during the tutorial?
- What went well during the tutorial?

Before you prepare for the next lecture, it is a good idea to meet with all people involved in the course, especially if you are not the only lecturer in a course, as is often the case. You need to be able to transfer or receive information about what happened in the previous lecture(s).

5.2 Evaluation form

The evaluation form at the end of a course will contain some standard questions. Very often students are asked to fill in a form to give feedback on the course after they have

https://doi.org/10.1515/9783110569582-005

taken the final exam, or during the last lecture/ teaching activity. This will be organized by your institution. In that case you will receive the results afterwards. Normally you will need to give a reaction about the feedback from the forms.

In these forms a Likert scale (Likert, 1978) using five items is very often used (indicating a scale of: I agree strongly — I agree — I am neutral — I disagree — I disagree strongly) for a number of standard questions about the organization like:
- The overall quality of the course was adequate.
- The overall program was coherent.
- The level of the course was what I expected.
- The lectures were well organized.
- The study guide was clear.

And also about the way the lecturer(s) taught, and the way the TAs functioned:
- The lecturer developed clear themes in his lectures.
- There were enough interactive moments during the lecture.
- The lecturer explained concepts well.
- The lecturer was able to respond to questions clearly.

The literature:
- The literature provided helped in understanding the concepts.
- The provided problems helped me understand the concepts

The assessment:
- The level of the test was what I expected.
- The tutorials and the lectures helped me prepare for the test.
- The questions and tasks in the test were formulated clearly

In each category, there should be room for open comment, asking students for items that went exceptionally well, and things that could be improved.

5.3 Evaluation of the summative assessment

The summative assessment will give an indication whether or not you have reached your learning goals. Analysis of the test will also give an indication how well the test was able to measure the achievement of learning goals. If a large percentage of students was not able to give an answer to a particular question in the way you expected them to, either something was wrong in their preparation or in the way the question was formulated. It may have been too difficult or not formulated clearly.

In general, the results of a final test will look somewhat like the distribution given in the previous chapter — a group scoring with an average between 55% and 90% and a group scoring an average of about 25—30% or less. This is a normal distribution for a written exam with problems. There are always students who do not prepare for an exam. If, however, as in the example the low scoring group is too large, something has gone wrong. If such a large group dropped out or lost the connection to the course, it was too difficult for them. You will need to find out what went wrong. Normally your formative assessment should have alerted you to these problems. Most faculties will not accept a score in which 40% of the students fail a course. They will demand some sort of explanation. They will also expect you to make an adequate analysis of the cause of the problem and a proposal to improve the situation.

5.4 The improvement plan

The improvement plan is based on the results of the evaluation steps you have taken. It is the standard step in a design cycle, like a Plan—do—check—act cycle. Once you have executed a design, you will adjust it based on the evaluation, so it will give better results the next time you use it. In education, however, you have to deal with more uncertain situations. While molecules will have a predictable reaction to changing conditions, this is not true for students. Student groups change from year to year. The way they react to your course may differ as well. The background of students is also an important factor. Engineers are trained different from organic chemists in the way they approach a problem.

6 Professional development

In most cases your appointment at an institution will entail both research and teaching. Strangely enough tenure decisions are often made with a high emphasis on research accomplishments and not on teaching. While you will have an extensive training of at least 6 years as a researcher, your training as a teacher is often neglected. Countries are beginning to adopt a strategy in which lecturers are required to obtain some sort of University Teaching Qualification.

Like the development of research abilities, the development of your teaching abilities is a continuous process. It begins with the teaching you experienced yourself. You will have had 50 to 100 different teachers when you reach the level where you will be lecturing. They have set many examples for you. Some you found inspiring, others you found dull. You will tend to take one of those as an example. You have to be careful about using your own learning experience as a guide for your own teaching. You are an exceptional case. Only 5% of students make it to a professorial level. That means that the average student will have a different learning pattern than you had.

When you design a course, you go through a cycle, which is depicted in Figure 6.1. This is loosely based on work by Loucks-Horsley et al. 1999).

Starting at the left you decide on the science content taking into account what you know about student learning, and taking into account the context of the course and the background of the students. These are combined in setting the learning goals. Once you have formulated the learning goals, you combine these with your knowledge about teaching strategies. These yield a plan for the course, which is then executed, applying the relevant teaching strategies you have at your disposal. Once the course is executed, it is evaluated. The evaluation gives you data about problems that were encountered during the courses. These add to your knowledge and beliefs about teaching.

The experience you have had including the evaluation play a role in your professional development as a teacher. Main part in your professional development as a teacher lies in your knowledge and beliefs, combined with the skills you have as a teacher. This is illustrated in Figure 6.2.

The external sources as well as professional development courses are an important factor. They provide both input in the theoretical background of teaching activities and theoretical background about learning.

Most science conferences will have sessions about education. Sharing your experiences is important. Articles in, for example, the *Journal of Chemical Education* or the *Journal of College Science Education* contain many good practice examples of teaching. These can serve as an inspiration for yourself.

One of the important factors in your professional development as a lecturer is the realization that things can and will go wrong. Just like it takes time to fine-tune an experiment, it takes time to develop teaching activities in such a manner that they are

https://doi.org/10.1515/9783110569582-006

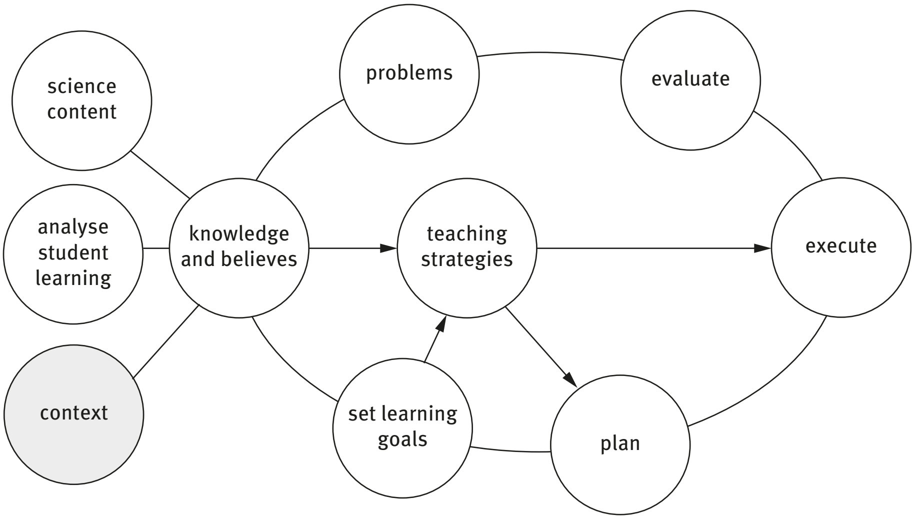


Figure 6.1: Cycle of a teacher's development, based on Loucks-Horsley et al. (1999).

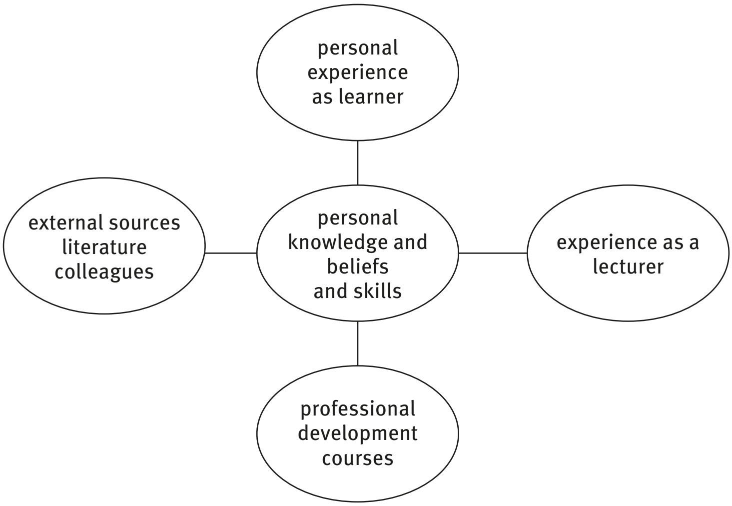


Figure 6.2: Personal development as a teacher.

effective in the learning process of your students. You have to give yourself enough leeway to find out how to optimize learning activities.

Reflecting on your own role as a teacher is just as important as getting feedback on your role as a teacher. A relatively new technique, called 360 degree feedback (Tee & Ahmed, 2014), will help you reflect on your own functioning as a lecturer. It will give you feedback from different sources, from yourself, your students as well as your peers. It will give insight into your strong points as well as your weak points.

Basically, it can serve as a guide for future development. You will need to find a coach however in order to do this effectively (Dyer, 2001). You need someone to discuss the results with you but also someone to help you formulate the questions to be used in the questionnaires.

When you reflect on your teaching, questions like the following could be answered by you and others:

- What is your role as a lecturer? What are your responsibilities?
- What are your strong points in education?
- How have you improved your educational activities?
- Which improvements do you wish to realize?
- How do you motivate and activate your students?
- Which teaching activities do you think to be effective?
- How do you integrate your own research in your education?
- Which aspects in teaching do you wish to develop further?

Both your own answers to these questions and the answers from your peers and your students about you will help you get a better view of yourself as a teacher.

Literature Cited

Anderson, L. W., & Krathwohl, D. R. (2001a). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives* (Abridged e). New York: Longman.

Anderson, L. W., & Krathwol, D. R. (2001b). The knowledge dimension. In L. W. Anderson & D. R. Krathuol (Eds.), *A taxonomy for learning, teaching and assesing (a Revision of Bloom's taxonomy of educational objectives*. New York: Addison Wesley Longman.

Apotheker, J. H. (2004). Introducing cooperative learning in the chemistry classroom. In *18th International Conference on Chemical Education*. Istanbul.

Aronson, E., & Patnoe, S. (1996). *The Jigsaw classroom: Building cooperation in the classroom* (2nd edn.). San Francisco: Allyn&Bacon.

Aslan, B., & Seker, H. (2017). Interactive Response Systems (IRS) Socrative application sample. *Journal of Education and Learning*, 6(1), 167–174. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ1120823&site=ehost-live&scope=site

Barth-Cohen, L. A., Smith, M. K., Capps, D. K., Lewin, J. D., Shemwell, J. T., & Stetzer, M. R. (2016). What are middle school students talking about during clicker questions? Characterizing Small-group conversations mediated by classroom response systems. *Journal of Science Education and Technology*, *25*(1), 50–61. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ1087655&site=ehost-live&scope=site

Bertona, C., Kleijn, E. de, Hennink, D., Apotheker, J. H., Drooge, H. van, Waals, M., … Lune, J. van. (2014). *Scheikunde VWO, Syllabus Centraal Examen 2016*. Utrecht: College voor examens.

Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher Education*, *32*(3), 347–364.

Black, P., & Wiliam, D. (1998). Inside the black box. *Phi Delta Kappa*, *80*(2), 139–144.

Bloom, B. S. (1984). *Taxonomy of educational objectives: Book 1 cognitive domain*. Reading, MA: Addison Wesley.

Bloxham, S., den-Outer, B., Hudson, J., & Price, M. (2016). Let's stop the pretence of consistent marking: Exploring the multiple limitations of assessment criteria. *Assessment & Evaluation in Higher Education*, *41*(3), 466–481. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ1093500&site=ehost-live&scope=site

Bowen, C. W., & Phelps, A. J. (1997). Demonstration-based cooperative testing in general chemistry: A broader assessment-of-learning technique. *Journal of Chemical Education*, *74*(6), 715–719.

Bransford Brown, A. L., & Cocking, R., J. D. (2000). *How people learn*. Washington D.C.: National Academy Press.

Broadfoot, P., Daughtery, R., Gradner, J., Harlen, W., James, M., & Stobart, G. (2012). assessment for learning. Retrieved November 21, 2017, from https://assessmentreformgroup.files.wordpress.com/2012/01/10principles_english.pdf

Buck, L. L., Bretz, S. L., & Towns, M. H. (2008). Characterizing the level of inquiry in the undergraduate laboratory. *Journal of College Science Teaching*, *38*(1), 52–58.

Bybee, R. W., Powell, J. C., & Towbridge, L. (2007). *Teaching secondary school science, strategies for developing science literacy* (9th edn.). Upper Saddle river, N.J.: Pearrson.

Chaplin, S. (2007). A model of student success: Coaching students to develop critical thinking skills in introductory biology courses. *International Journal for the Scholarship of Teaching and Learning*, *1*(2). Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ1136938&site=ehost-live&scope=site

Cooper, M. (2014). Evidence-based reform of teaching and learning. *Analytical & Bioanalytical Chemistry*, *406*(1), 1–4. Retrieved from http://10.0.3.239/s00216-013-7438-4

https://doi.org/10.1515/9783110569582-007

Derounian, J. G. (2017). Inspirational teaching in higher education: What does it look, sound and feel like? *International Journal for the Scholarship of Teaching and Learning*, *11*(1). Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ1136124&site=ehost-live&scope=site

Duit, R., Gropengießer, H., Kattmann, U., Komorek, M., & Parchmann, I. (2012). The model of educational reconstruction- A framework for improving teaching and learning science. In D. Jorde & J. Dillon (Eds.), *Science education research and practice in Europe, retrospective and prospective* (pp. 13–39). Rotterdam: Sense Publishers.

Duschinsky, R. (2012). Tabula Rasa and human nature. *Philosophy*, *87*(4), 509–529. Retrieved from http://10.0.3.249/S0031819112000393

Dyer, K. M. (2001). The power of 360-Degree feedback. *Educational Leadership*, *58*(5), 35. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=aph&AN=4526792&site=ehost-live&scope=site

Dykstra, E. (2018). *Differences in motivation and prediction of academic success: A study of American and international college students. Dissertation Abstracts International Section A: Humanities and Social Sciences*. ProQuest Information & Learning, US. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=psyh&AN=2017-19718-290&site=ehost-live&scope=site

Fechete, I. (2016). Dmitri Ivanovich Mendeleev: The Sanctus Sanctorum of the art in the establishment of the first periodic table of the elements. *Comptes Rendus Chimie*, *19*(1/2), 11–16. Retrieved from http://10.0.3.248/j.crci.2016.01.006

Fountain, K. R., & McGuire, B. R. (1994). Understanding, mastery-active learning, and HYPERCHEM: Experiments with MO theory. *Journal of Chemical Education*, *71*(11), 938. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=aph&AN=9412123117&site=ehost-live&scope=site

French Embassy NY French,Cultural Services, N. Y. (1971). *Education in France: Number 41*. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=ED046301&site=ehost-live&scope=site

Gallardo-Williams, M. T., & Petrovich, L. M. (2017). An integrated approach to Training Graduate Teaching Assistants. *Journal of College Science Teaching*, *47*(1), 43–47. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=aph&AN=124798867&site=ehost-live&scope=site

Gardner, H. (1993). *Frames of mind, the theory of multiple intelligences*. London: Fontana Press.

Glickman, C. D., & Gordon, S. P. (n.d.). Clarifying developmental supervision. *Educational Leadership*, *44*(8), 64. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=snh&AN=8721817&site=ehost-live&scope=site

Gok, T. (2015). An investigation of students' performance after peer instruction with stepwise problem-solving strategies. *International Journal of Science and Mathematics Education*, *13*(3), 561–582. https://doi.org/10.1007/s10763-014-9546-9

Groot, A. D. de. (1946). *Het denken van den schaker*. University of Amsterdam.

Hofstein, A., & Lunetta, V. N. (1982). The role of the laboratory ins cience teaching:negelcted aspects of research. *Review of Educational Research*, *52*(2), 201–217.

Hooijmaaijers, T. (2000). *Bron en Perspectief, Het belang van Jenaplan, Montessori, Dalton, Freinet en de Vrije School voor het basisonderwijs*. *Pabo-katernen*. Heeswijk-Dinther: Esstede.

Huisman, E. H., Bakker, F. L., van der Pal, J. P., de Jonge, R. M., & van der Wal, C. H. (2011). Public exhibit for demonstrating the quantum of electrical conductance. *American Journal of Physics*, *79*(8), 856–860. https://doi.org/10.1119/1.3593276

Johnson, D.W., & Johnson, R.T. (1999). *Learning together and alone* (5th edn.). Boston: Allyn and Bacon.

Johnstone, A. H. (1997). Chemistry teaching- science or alchemy. *Journal of Chemical Education*, *74*(3), 262–268.

Johnstone, A. H. (2010). You can't get there from here. *Journal of Chemical Education*, *87*(1), 22–29.

Kagan, S. (1990). The structural approach to cooperative learning. *Educational Leadership*, *47*(4), 12–15.

Keller, V. A., & Kendall, B. L. (2017). Independent synthesis projects in the organic chemistry teaching laboratories: Bridging the gap between student and researcher. *Journal of Chemical Education*. https://doi.org/10.1021/acs.jchemed.7b00093

Kennedy, J., Lyons, T., & Quinn, F. (2014). The continuing decline of science and mathematics enrolments in Australian high schools. *Teaching Science*, *60*(2), 34–46. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ1048771&site=ehost-live&scope=site

Likert, R. (1978). *A technique for the measurement of attitudes*. Ann Arbor Michigan: Univesity of Michican.

Lionni, L. (1970). *Fish is fish*. New York: Dragonfly Books.

Locke, E. A., & Latham, G. P. (2002). Building a practically useful theory of goal setting and task motivation. *American Psychologist*, *57*(9), 705–717. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ654871&site=ehost-live&scope=site

López, G. A., Sáenz, J., Leonardo, A., & Gurtubay, I. G. (2016). Use of the "Moodle" platform to promote an ongoing learning when lecturing general physics in the physics, mathematics and electronic engineering programmes at the University of the Basque Country UPV/EHU. *Journal of Science Education and Technology*, *25*(4), 575–589. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ1106647&site=ehost-live&scope=site

Loughran, J., Berry, A., & Mulhall, P. (2006). *Understanding and developing science teachers' pedagocical content knowledge*. Rotterdam: Sense Publishers.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in Science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching*, *41*(4), 370–391.

Mann, S., & Robinson, A. (2009). Boredom in the lecture theatre: An investigation into the contributors, moderators and outcomes of boredom amongst university students. *British Educational Research Journal*, *35*(2), 243–258. Retrieved from http://10.0.4.56/01411920802042911

Mattei, M. D., & Ennis, E. (2014). Continous, Real-Time Assessment of every student's progress in the flipped higher education classroom using nearpod. *Journal of Learning in Higher Education*, 10(1), 1–6.

Mayer, R. E. (2009). *Multimedia learning* (2nd edn.). Cambridge: Cambridge University Press.

Mazur, E. (1997). *Peer instruction, a user's Manual*. Upper Saddle river, NJ: Prentice Hall.

McNally, B., Chipperfield, J., Dorsett, P., Del Fabbro, L., Frommolt, V., Goetz, S., … Rung, A. (2017). Flipped classroom experiences: Student preferences and flip strategy in a higher education context. *Higher Education*, *73*(2), 281–298. https://doi.org/10.1007/s10734-016-0014-z

Montessori, M. (1912). *The montessori method* (20th edn.). New York: Schocken books.

Morsch, L. A., & Lewis, M. (2015). Engaging organic chemistry students using ChemDraw for iPad. *Journal of Chemical Education*, *92*(8), 1402–1405. Retrieved from http://10.0.3.253/acs.jchemed.5b00054

Mullis, I. V.., & Martin, M. O. (2015). *TIMSS 2015 assessmentframeworks*. Boston. Retrieved from https://timssandpirls.bc.edu/timss2015/frameworks.html

Mundry, S., Loucks-Horsley, S., & National Inst. for Science Education WI., M. (1999). *Designing professional development for science and mathematics teachers: Decision points and dilemmas. NISE Brief* (Vol. 3). NISE Brief. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=ED430810&site=ehost-live&scope=site

Nentwig, P. M., Demuth, R., Parchmann, I., Gräsel, C., & Ralle, B. (2007). Chemie im Kontext: Situated learning in relevant contexts while sytematically developing basic chemical concepts. *Journal of Chemical Education*, *84*(9), 1439–1444.
Novak, J. D. (1978, January). An alternative to Piagetian psychology for science and mathematics education. *Studies in Science Education*. Studies in Science Education. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ187330&site=ehost-live&scope=site
Nurrenbern, S. C. (2001). Piaget's theory of intellectual development revisited. *Journal of Chemical Education*, *78*(8), 1107–1110.
Offerdahl, E. G., & Tomanek, D. (2011). Changes in instructors' assessment thinking related to experimentation with new strategies. *Assessment & Evaluation in Higher Education*, *36*(7), 781–795. Retrieved from http://10.0.4.56/02602938.2010.488794
OPCW, working group. The Hague Ethical Guidelines (2015). The Netherlands. Retrieved from https://www.opcw.org/special-sections/science-technology/the-hague-ethical-guidelines/
Osborne, J., & Dillon, J. (2008). *Science education in Europe: Critical reflections a report to the Nuffield foundation*. London: The Nuffield Foundation.
Reid, S. A. (2016). A flipped classroom Redesign in general chemistry. *Chemistry Education Research and Practice*, *17*(4), 914–922. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ1116274&site=ehost-live&scope=site
Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H., & Hemmo, V. (2007). *Science education now: A renewed pedagogy for the future of Europe* (Vol. EUR 22845). Brussels: European Commission.
Sayers, D. L. (1995). *The documents in the case*. London: Harper Torch.
Scerri, E. R. (2003). Philosophical confusion in chemical education research. *Journal of Chemical Education*, *80*(5), 468,470–472,474–477. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ666902&site=ehost-live&scope=site
Schwarz, P., & Heimann, R. (2016). Trainieren von kognitiven Grundfertigkeiten im Chemieunterricht – eine Möglichkeit zur Förderung des naturwissenschaftlichen Denkens? *Chemkon – Chemie Konkret*, *23*(2), 79–85. Retrieved from http://10.0.3.234/ckon.201610263
Siegel, M., Roberts, T. M., Freyermuth, S. K., Witzig, S. B., & Izci, K. (2015). Research and teaching: Aligning assessment to instruction – Collaborative group testing in large- enrollment science classes. *Journal of College Science Teaching*, *44*(6). Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ1093985&site=ehost-live&scope=site
Silberberg, M., & Amateis, P. (2015). *Chemistry, the molecular nature of matter and change* (7th edn.). New York: McGraw-Hill.
Sjøberg, S., & Schreiner, C. (2010). *The rose project. An overview and key findings*. Oslo. Retrieved from http://www.roseproject.no/publications/english-pub.html
Slavin, R. E. (1995). *Cooperative learning* (2nd edn). Boston: Allyn and Bacon.
Smith, G. (2007). How does student performance on formative assessments relate to learning assessed by exams? *Journal of College Science Teaching*, *36*(7), 28–34. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ769007&site=ehost-live&scope=site
Swiderski, S. M. (2011). Transforming principles into practice: Using cognitive active learning strategies in the high school classroom. *Clearing House: A Journal of Educational Strategies, Issues and Ideas*, *84*(6), 239–243. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ950411&site=ehost-live&scope=site
Tee, D. D., & Ahmed, P. K. (2014). 360 degree feedback: An integrative framework for learning and assessment. *Teaching in Higher Education*, *19*(6), 579–591. Retrieved from http://10.0.4.56/13562517.2014.901961

Tofan, D. C. (2009). Improving chemistry education by offering salient technology training to preservice teachers: A graduate-level course on using software to teach chemistry. *Journal of Chemical Education*, *86*(9), 1060–1062. Retrieved from http://search.ebscohost.com.proxy-ub.rug.nl/login.aspx?direct=true&db=eric&AN=EJ853493&site=ehost-live&scope=site
van, der P. (2014). The salient history of Dalton education in the Netherlands. *History of Education*, *43*(3), 368–386. https://doi.org/10.1080/0046760X.2014.887792
Vasquez-Abad, J. (1999). "Hebdo-Chim," a web application to support learning in a chemistry methods pre-service course. *Journal of Science Education and Technology*, *8*(4), 283–290.
Vosniadou, S. (2010). *How Children learn, educational practices series-7*. http://www.iaoed.org/index.php/ed-practices-series: The International Academy of Education.
Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge: Harvard University Press.
Way, C. (2015). *The millenium goals development report 2015*. New York: United Nations.
Ziegler, A., & Heller, K. A. (2000). Conditions for self-confidence among boys and girls achieving highly in chemistry. *Journal of Secondary Gifted Education*, *11*(3), 144–151.

List of figure sources

Figures P.1; P.2; P.3	adapted from the Rose report
Figure 1.1	downloaded from https://upload.wikimedia.org/wikipedia/commons/6/67/Jean_Piaget_in_Ann_Arbor.png
Figure 1.2	self made
Figure 1.3	downloaded from https://upload.wikimedia.org/wikipedia/commons/8/8f/Lev_Vygotsky_1896-1934.jpg
Figure 1.4	self made
Figure 1.5	adapted from Johnstone
Figure 1.6	self made
Figure 1.7	self made
Figure 2.1	downloaded from https://www.flickr.com/photos/jurgenappelo/6943419159/in/photolist-bzyQBr-qdnzke-9r7sTb-8ZFKcG-p4RvD2-8M6N49-9cgQko-rPyvZL-UZ6Pxm-Vmu8jn-aYxDwX-7nrLuW-q3Fmpc-fc4BHy-qML2SA-i1kQd-fAsDkd-q9hope-evDgam-a8qGbo-4UGGsM-549pUG-s7mL11-ssCPRa-cvpMX5-SReobh-8PYXvC-8LpfHX-VehPSd-8MpH7U-qXYptf-r3Lf3F-7nnRN6-6bLxvA-cgNsVo-qLacVp-7nnRPk-r1DDLJ-qdshg1-ejwMvN-na8r1h-7xXASL-p8ZJuw-dod2Ec-qdA6Ck-ew46JX-nC4nm1-qt538H-qdA6BP-W8sDYW
Figure 2.2	downloaded from https://www.flickr.com/photos/wendt-library/5190902114/in/photolist-8UGJmj-V12UxW-V12UYq-UtrEcJ-dL65Rh-S4eP7Y-6XZFMc-S4eP6f-cEJpCY-pDCGUW-bAjoHK-dJB9vk-5GRxjd-cEJH2A-4Vc87N-e4JAPP-f9Qx7B-e2sE9j-cEJnWs-cEHT61-cEHss5-6GCwzk-fPxGqz-oGrvn-eHUHz4-axJmPN-RJQgiN-bBqH9p-U1fsQJ-dL19PP-U46v5T-bt7A76-S3Y6qY-RtCD8e-dKtTqo-avuqbe-fa5Nk5-fa5MRj-dHsmNn-fa5N7Y-544TtB-Yabvcw-DCrzo-V12WjS-UP9DfQ-9o9hiQ-i79vne-qfspda-4VQmn8-TcWKW1
Figure 2.3	self made
Figure 2.4	self made
Figure 2.5	downloaded from https:// commons.wikimedia.org/wiki/File:Blackboard_Inc._logo.png
Figure 2.6	self made screenshot
Figure 2.7	self made screenshot
Figure 3.1	Luke Jones, Lecture: Chemistry at Colorado School of Mines, downloaded from https://www.flickr.com/photos/befuddledsenses/16662127930/in/photolist-ronL8L-oyg5xH-4eRS8Z-KAmf2a-JLFut9-owYGXK-9C1qxi-7gBq8u-drV4WL-owifiy-JbXpyJ-JLMw1V-nUy9D4-drV5oA-drV3pQ-drV383-6fUKMr-ofKViq-XZhG3b-aCXU4G-drUWB2-drV2Jw-owYrhB-LqHTG-drV3LQ-9qtFU7-

https://doi.org/10.1515/9783110569582-008

Index

https://doi.org/10.1515/9783110569582-009