A Guidebook of Good Practice for the Pre-Service Training of Chemistry Teachers

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Design of Learning and Assessment Tasks

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Why is this topic important in Pre-Service teacher (PST) education?

In previous chapters, the complexity of perspectives on learning and the challenging abstract nature of chemistry concepts have been highlighted. It is clear from these discussions that teaching and learning of chemistry is multifaceted and not simplistic. In order to teach effectively, PSTs need to be able to design and plan learning sequences that help learners construct an understanding of chemistry concepts. Furthermore, as part of these learning sequences, they need to embed opportunities to determine whether students have constructed or understood these concepts in a meaningful way. In this chapter we will provide a theoretical background as well as practical examples demonstrating how these essential teaching skills can be developed by PSTs.

What is covered in this chapter?

This chapter builds upon what has been discussed in other chapters such as 'Educational Theories and How Students Learn Chemistry: Practice what you Preach', 'Understanding and Using Chemistry Curricula for Effective Teaching' and 'Students' Alternative Conceptions and Ways to Overcome them and focusses on enabling the chemistry PST to develop competence in planning appropriate teaching/learning/assessment processes for their classes.

In the first section of this chapter a theoretical framework gives background information on designing learning and assessment tasks. Learning and assessment are fundamentally entwined, thus rich learning tasks can also serve as valuable assessment tasks. It is important to realise that the triumvirate of assessment practices, curricula and learning pedagogies are all inter-related and that each must complement the other for effective learning. One of the challenges in PST education is to break down their prior experiences of schooling in terms of learning and assessment and to ensure that PSTs experience varied approaches and assessment practices within their education programmes.

In the second section of this chapter, four examples of good practice will be provided. These will outline strategies to introduce PSTs to learning and assessment task design. All four demonstrate the interrelatedness of learning and assessment, though in the discussion, the first two will be predominately explained in the context of learning task design (planning, sequencing, cognitive development) and the emphasis in the second two examples will concentrate on assessment (peer-learning, criteria-based and assessment of discourse).

Theoretical Framework

This section highlights the importance of design of learning tasks and the basis of assessment.

Learning Tasks

Learning science is associated with constructing meaning and developing an understanding of the world around us. Teachers need to engage students in interesting scientific scenarios (situations, events, tasks and activities) that provide opportunities for development of questioning / investigation skills, conceptual understanding and thinking skills through reflection on the process.

A core teacher competence is the ability to plan and design such learning tasks. In the process of planning, the teacher combines knowledge and skills from various fields of chemistry, chemistry didactics, pedagogy and psychology. The teacher selects the chemistry facts, concepts and examples, decides on the level of explanation and determines the teaching and learning methods, experiments, necessary equipment and other aids according to the teaching and learning aims and outcomes. They design learning tasks according to their teaching and learning aims and outcomes and deploy extensive repertoires of skills and strategies, bearing in mind the particular student class (ability level, prior knowledge, class size etc). They must also be aware of having to change and modify their tasks, making decisions and acting in unplanned situations.

In order to design learning tasks teachers need to be cognisant of learning theories and the specific challenges in learning chemistry due to its abstract nature. Specifically they need to understand how to appropriately sequence learning tasks so students can make coherent and logical links between concepts and to foster students' conceptual understanding. The process of construction of scientific knowledge and the cognitive development of the students are dependent upon the interaction of his / her cognitive structures, and the structures of scientific knowledge organized into systems that are provided by the curricula. It is difficult to apply approaches suitable for the needs and learning styles of each individual, but the application of a wide range of teaching and evaluation strategies brings the contents and learning process closer to the interests and styles of a larger number of students.

Teachers require the ability to adapt their plans and practices to meet students' learning needs within the field of science teaching (Vogt and Rogalla, 2009). Chemistry teachers need a deep knowledge of both their subject and of teaching chemistry (PCK) as well as an ability to adapt practice in diverse and inclusive learning environments (Bindernagel and Eilks, 2009; Yakmaci-Guzel, 2013). Epistemological awareness is also necessary: the knowledge and understanding of historical, cultural and structural features of chemistry linked with other subjects across the curriculum. Knowledge of education theories, school curricula, class management, teaching/learning methods and assessment should be connected with the chemistry teaching/learning aims and general aims of second level education. Also, reflective, interpersonal skills for learning in professional communities are important.

Developing students' thinking is an essential part of teaching/learning. A number of pedagogies have been developed to encourage students' engagement and thinking in science such as Inquiry methods (see also the "Chapter Inquiry Based Chemistry Instruction") and Concept based methods. This chapter gives examples and theoretical backgrounds of other approaches including concept mapping, discourse and cognitive acceleration.

Assessment Tasks

Quality teaching requires systematic assessment of knowledge and skills/competencies according to education theories, research, professional experience and evidence. PSTs thus need to have an understanding of theoretical and practical underpinnings of assessment.

> The term assessment has many meanings and interpretations. In its broadest sense, it can be used for two main purposes to evaluate students: (a) for grading, tracking or to give comparisons between student sets, locally, nationally or internationally; (b) as diagnostic to give feedback (both to the student and the teacher) on achievement of learning outcomes.

Assessment is often labelled as being either summative or formative where the distinction between the two relates to what the output of the assessment is used for and not the type of assessment. **Assessment of learning (summative)** is used as a final evaluation of the learning that has occurred and is often presented in the form of grades. Summative assessments are habitually conducted by external bodies and hence teachers are inclined to use a similar type of assessment within their teaching, hence influencing strongly both the teaching methods and the content (Harlen, 2007). This can lead to the overuse of frequent summative assessments within teaching (Black and Wiliam, 1998).

Formative assessment (**assessment for learning**) is assessment that is used throughout the learning process in order to advance the learning and provide students with feedback that should direct and encourage further learning. This type of assessment both enhances the student learning but also informs teachers of their next steps in instruction. It is an integral part of the teaching and learning process. It is continuous and actively engages students in peer- and self- assessment. Formative assessment supporting learning, involves the process of seeking and interpreting evidence for use by learners and their teachers to decide where the learners are in their learning, where they need to go and what is the best way to get there (Klassen, 2006; Hattie and Timperley, 2007).

Key features of formative assessment are that it takes place during the learning process and not after it; it provides an immediate and detailed feedback for the students and/or teacher; and the assessment information is used to modify the learning process to make it more effective. It is important to note that the time between collecting information on learning outcome and feeding back to learners has to be short to maintain and improve learning process (Wiliam, 2013; Havnes, Smith, Dysthe & Ludvigsen, 2012).

A good assessment should provide information that is useful for diagnosis, feedback and the design of the next steps for the instruction (Pellegrino *et al.,* 2001). Assessments that make students' thinking visible and explicit, engages students in the self-monitoring of their learning, makes the features of good work understandable and accessible to students and provides feedback specifically targeted towards improvement, are effective assessments (Shepard, 2003). Therefore, when designing and planning learning tasks, it is important for PSTs to think about the opportunities within the learning experience for both teachers and students to review and challenge their understanding.

PSTs should be exposed to a range of assessment methods and techniques including questioning, observation, peer-assessment, portfolios (including student artefacts such as laboratory reports examples of writings, models etc.), student presentations, how to provide feedback, how to design tests, how to design assessment criteria, how to use rubrics etc.

PSTs should also be made aware of common pitfalls when assessing learning and progress. For example, PSTs tend to rely on lower order, recall or 'initiate-response-evaluate' style questioning and transmission style activities and often make the assumption that if their students can recall a fact or give one word responses, that they have grasped the concept. Other common issues include: over assessing and/or collecting too much information that is not realistic to evaluate, using a limited range of assessment types thus preventing students with opportunities to show their learning, not being clear on what evidence they are looking for, and not matching the assessment to the learning outcomes. For example, if critical scientific reasoning is an important goal in chemistry teaching, then monitoring and testing achievements require adequate tasks which will determine the level and the quality of student's reasoning (Cloonan and Hutchinson, 2011).

Entwined Nature of Learning and Assessment Tasks

Learning and assessment are totally entwined and often it is the assessment that drives learning. Therefore it is important that assessment practices actually assess what needs to be assessed rather than what is easy or convenient to assess and that assessment practices actually promote the learning. This point emphasises the importance of assessment practices being considered within the planning phase and that the tasks and activities planned develop content knowledge but can also be used in assessment. Where formative assessments are used, the teacher needs to use assessment evidence to plan and design the follow on learning tasks to help students' development. To this end, it is important to help PSTs realise that the triumvirate of assessment practices, curricula and learning pedagogies are all inter-related and that each must complement the other for effective learning. Therefore in PST education, tasks that clearly show learning processes with assessment are important to highlight a range of assessment opportunities possible within lessons.

Several excellent reviews of assessment in science are available and recommended for reading such as Black & Wiliam, 2009, Harlen, 2013. A good general practical guide to assessment can be found in A Guide to Teaching Practice, Cohen, Manion and Morrison, 2004.

Examples of good practice

In this section, four examples of good practice are provided to offer PST educators possible strategies for introducing PSTs to learning and assessment task design. The first two examples concentrate on design of learning tasks and the remaining two emphasise assessment strategies. All four examples highlight the entwined nature of learning and assessment.

PSTs need to experience a variety of pedagogies themselves so that they can internalise them and then develop them into their own practice. We advocate this perspective on PST education and therefore the examples offered have a common implementation in that:

a) PSTs complete the tasks as learners,

b) they critically reflect on the tasks and

c) they consider how the tasks can be adapted and integrated into their own practice.

Good Practice Example 1: Exploring concept mapping as a tool to help effective sequencing of learning tasks

The selection of teaching/learning content, examples, and experiments in a lesson plan preparation is based on a concept map. In the process of thinking, concepts are the most important because they serve as organizers of all intellectual and cognitive activities, as well as of all kinds of communication (teacher-students, students-students, students-taught topics). Since they are the main thinking tool, their organization in cognitive structures is of great importance. In this example, concept maps are used to plan, design and sequence learning tasks.

A concept map is a teaching tool in which connections and relations, as well as the hierarchy of concepts, are presented in an obvious way. The development of concept maps can help PSTs understand how chemistry concepts are linked, resulting in a deepening of their knowledge of the disciple. The task gives PSTs a systematic approach to the planning process of lessons, focuses them on the choice of illustrations (examples), experiments, explanations that help their students to build an understanding of concepts and establish connections between them, i.e. the formation of the basis for understanding chemistry.

The opportunity to construct a system of chemistry concepts based on experimental observation is an important part of chemistry teacher preparation associated with the transformation of chemistry knowledge into pedagogical chemistry knowledge. Through development of these concept maps PSTs can see that different experiments could be used for the formation of certain concepts and based on this experience, make decisions on which experiments are more appropriate in a particular teaching situation.

The task also has a formative assessment component in which peer learning and teacher-feedback are used. Critical reflection on this aspect of the task allows PSTs to appreciate how formative assessment can be beneficial in enabling students to receive feedback from the teacher or other students when faced with insufficient understanding of concepts and their interrelationships.

The use of the concept map also allows teacher educators to monitor PSTs reasoning, and their ability to determine the chemistry concepts that are important within that lesson plan. The completion of the task helps to enhance PSTs chemistry conceptual understanding, ability to observe regularities among data and to determine a system of chemistry concepts necessary for formulation of explanations.

The main features of this approach to develop PSTs' competence to plan teaching and learning tasks are:

- developing a model for planning lessons in a systematic way;
- clarification of the chemistry concepts system, i.e. the students' knowledge organization necessary for understanding the content of a lesson;
- using a concept map as a tool for systematic lesson planning and the basis for choosing lesson content, examples and experiments;
- using a concept map as a basis for deciding upon appropriate adaptions of content and student activities according to students' learning needs, interest and abilities;
- using peer-learning and peer-assessment as a method of formative assessment in the process of developing the competence to plan lessons;
- using student collaboration in the process of lesson planning, exchange of knowledge and ideas related to the elaboration of chemistry concepts;
- systematization of previously acquired knowledge in different chemistry courses as well as chemistry didactics, pedagogy and psychology courses;
- demonstrating a model of collaboration that could be used with colleagues in future schools when planning teaching and learning situations, and a model for future chemistry teachers to organize their work with second level school students in the classroom.

The task itself is divided into three key steps:

Step 1:	PSTs observe experimental demonstrations and then individually construct a concept map that includes all concepts relating to the observed experiments.
Step 2:	After making their own concept map, they exchange them among themselves and are then asked to evaluate the quality of responses: the number and organization (the relations and hierarchy) of concepts in maps. After that, the whole group is involved in discussion on the given maps.
Step 3:	PSTs are asked to plan appropriate teaching and learning tasks for elaboration of a particular theme in chemistry classes. On completion, the prepared plans are presented and discussed within the class.

The experience gained in Step 1, especially if the task is performed several times with different demonstrations, may help in future selections of experiments according to the lessons' aims and outcomes. Step 2 and Step 3 involve peer-learning and peer-assessment of the outputs of work. It enables students to compare and contrast different concept maps, to learn from each other, to reflect critically on the selection and hierarchy of concepts in their own solution and draw conclusions about what makes certain concept maps effective for understanding the experiments presented. The process of generating a solution to this kind of task enhances the development of students' ability to observe regularities among the data and to determine a system of chemistry concepts necessary for formulation of explanations. During this process, PSTs integrate their knowledge acquired in different chemistry courses during their study in order to create a conceptual framework.

In Box 1, an example of an activity to be used with PSTs is outlined. Figure 1 shows two examples of concept maps developed by PSTs during Step 1 of this activity.

Box 1: Example from chemistry didactics classroom

Step 1. PSTs observe demonstrations and individually construct a concept map as conceptual framework for the next experiments:

- Experiment 1: dissolution of ammonium nitrate from cold pack
- Experiment 2: dissolution of sodium hydroxide
- Experiment 3: hydration of sulphuric acid – ether cannon
- Experiment 4: explosion of the soap bubbles fulfilled with the oxygen-hydrogen gas mixture
- Experiment 5: hydration of unslaked lime - melting of ice

Step 2. PSTs exchange their concept maps among themselves and evaluate the quality of the conceptual framework for the demonstrated experiments presented by each map. Two students' maps are shown in Figure 1 as an illustration of different approaches to the same set of demonstrations: one student has started from the concepts of substances and changes of substances (Figure 1a), while another has started from the concept of enthalpy (Figure 1b). The first map (Figure 1a) offers a broader conceptual framework than the second (Figure 1b). Such differences in the maps provide a good basis for discussion with the whole group on the organization of knowledge and which map better contributes to it.

Step 3. PSTs plan the teaching/learning situations that enable second level school students (age of 15) to understand the energy exchange between a system and its surroundings. PSTs individually prepare a teaching/learning situation.

The teaching/learning situations are then presented and discussed:

- which situations are more appropriate in relation to the teaching/learning goal and expected outcomes from second level school chemistry curriculum
- which situations are more appropriate for students with particular interests or special needs
- which situations are more appropriate when using standard equipment in second level schools and require cheaper equipment and substances, etc.

Figure 1: Sample of completed PSTs concept maps (Step 1)

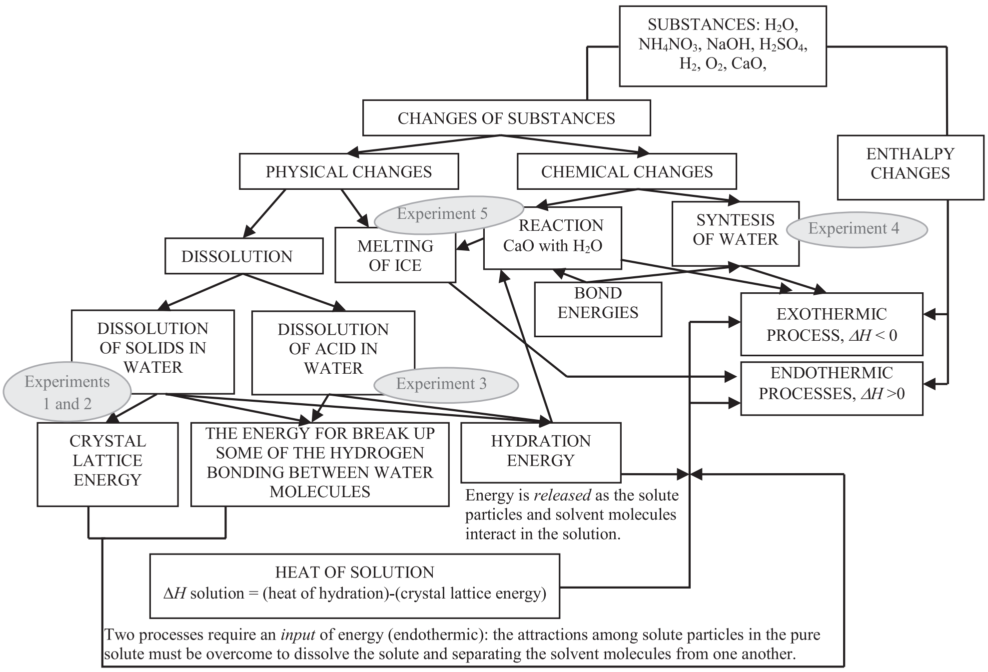


Figure 1a

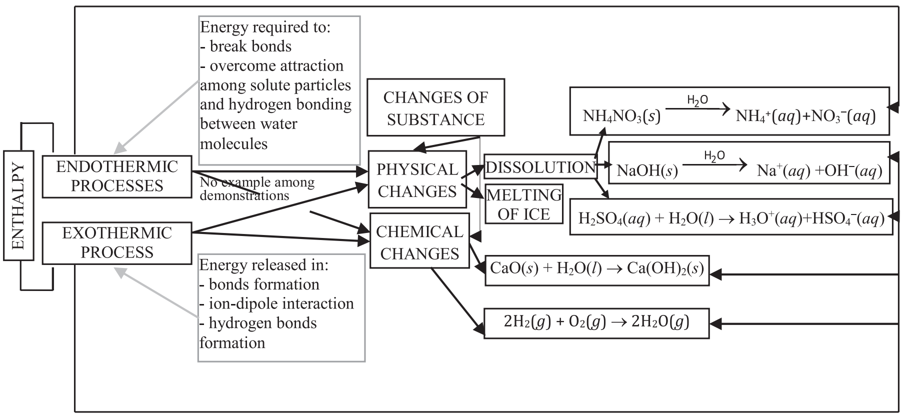


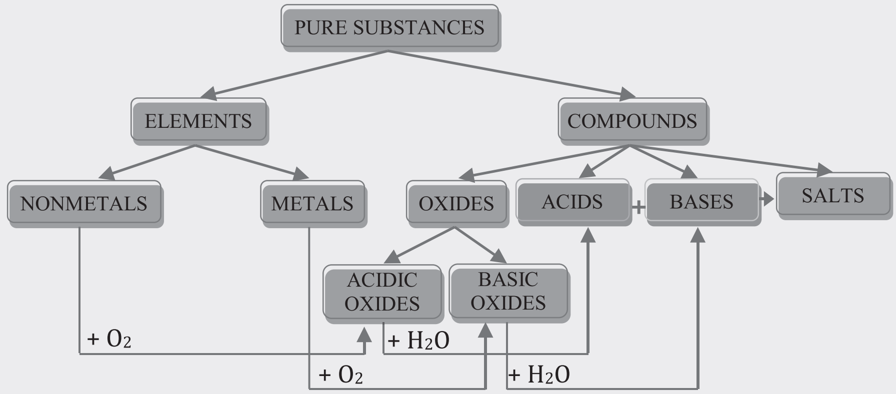
Figure 1b

This type of task has the potential to support development of PSTs' competence in relation to planning teaching/learning situations, to determine the relevant conceptual framework for understanding of a particular topic from the curriculum, to choose appropriate examples, illustrations and experiments. The opportunity to construct a system of chemistry concepts based on experimental observation is an important part of chemistry teacher preparation associated with the transformation of chemistry knowledge into pedagogical chemistry knowledge. Students can see that different experiments could be used for the formation of certain concepts and, on the basis of this experience, make decisions on which experiments are more appropriate in particular school situations.

In Figure 2, a proposed assessment activity is presented. This activity can be used to evaluate PSTs progress in developing their competencies to plan teaching and learning tasks. The assessment specifically examines their progress in selecting experiments for supporting formation of certain chemical concepts and their inter-relationships. These tasks are associated with the transformation of chemistry knowledge (conceptual knowledge and procedural knowledge) into pedagogical chemistry knowledge (the selection of appropriate experiments to support knowledge development of learners).

1) Suggest a concept map as a conceptual framework for the following experiments:
   - Obtaining hydrogen from zinc and sulphuric acid
   - Obtaining oxygen from $KMnO_4$
   - Synthesis of water
   - Electrolysis of water

2) Which of the experiments are appropriate for establishing the conceptual framework with focus on acids and bases as shown in the following map?



a) Determination of copper in a coin

b) The oxidation of hydrogen

c) Titration of sodium hydroxide with hydrochloric acid

d) Separating a sand and salt mixture

e) Making a mixture of iron and sulphur and separating them from each other

f) Determination of the pH range of a substance

g) Determination of the reactivity of acids with metals

h) Obtaining oxygen from $KMnO_4$

i) Combustion of sulphur and reaction of the oxide with water

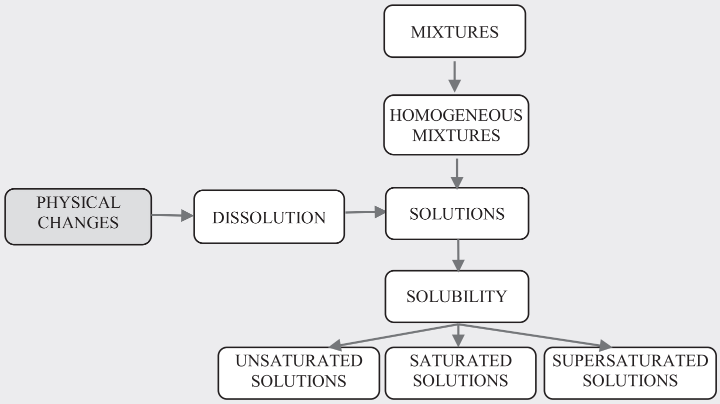
j) Combustion of magnesium and reaction of the oxide with water

k) An oscillating reaction

l) Mass conservation

m) The effect of temperature on reaction rate

3) Which of the experiments are appropriate for the following concept map?



a) Making a mixture of iron and sulphur	b) Dissolving of table salt in water
c) Preparation of saturated solution of table salt	d) Separating a sand and salt mixture
e) Determination of heat of reaction	f) Making a crystal garden
g) Preparation of supersaturated solution of sodium acetate	h) Determination of the reactivity of acids with metals
	i) The effect of temperature on reaction rate

Figure 2: Sample of PST Assessments

Good Practice Example 2: CASE – Cognitive Acceleration in Science Education

In Chapter "Educational Theories and How Students Learn Chemistry. Practice what you Preach", the work of Piaget relating to cognitive development has been introduced. Students at lower second level should be developing formal operational thinking, implying they are able to organise data, reason scientifically and generate hypotheses. Problems that were deemed impossible to solve at the concrete operational stage such as those involving combinatorial thought, complex verbal problems, hypothetical problems, proportions and ratio, are possible at the formal operational stage. In this case study, activities aimed at introducing PSTs to strategies that raise learners' cognitive level based on the Cognitive Acceleration through Science Education (CASE) programme are outlined.

The CASE programme, *Thinking Science* (Adey *et al.*, 1989) was designed to increase the proportion of second level students capable of formal operational thinking. The CASE lessons were designed around the schema of formal operations – which include control and exclusion of variables, ratio and proportionality, equilibrium, compensation, correlation, probability, compound variables and the construction of formal models – and build on five "pillars" (namely concrete preparation, cognitive conflict, social construction, metacognition and bridging). Three of the pillars (cognitive conflict, social construction and metacognition) will be elaborated on in relation to the design of tasks for learning and assessment.

Cognitive conflict is a term used to describe a dissonance that happens when a student is faced with an event/experience that he/she cannot explain using their current conceptual framework or reasoning skills. In each CASE lesson learners are presented with scenarios that induce cognitive conflict (these are different for learners according to their level of cognitive development) and they are supported in the construction of formal operational reasoning patterns to help bring new perspective to the event/experience. A cognitive conflict scenario must be within a context that is somewhat familiar to learners and it must not be too far ahead of their cognitive abilities while still making a real cognitive demand. This can be difficult to implement and one of the reasons that Adey (2004) cites for this is that teachers often find it difficult to watch their students struggle and possibly become frustrated or uncomfortable so they rush in with answers, which they feel are helpful. This of course defeats the purpose of the CASE pillar.

If cognitive conflict has disturbed the student's equilibrium, **construction is** the process that follows, where equilibrium is re-established through the development of a more powerful and effective way of thinking about the problem/event. The overall aim of the construction zone is to maximize the opportunity that each student has for constructing his or her reasoning patterns which he/ she will rely on for more powerful thinking in the future. Good CASE lessons include a great deal of on-task discussion and constructive argument in small groups and between groups, thus helping learners to verbalise their thinking and therefore making it explicit.

The third pillar focused on in this task is **metacognition**. This is an important part of developing thinking skills where learners become conscious of and articulate about the thinking they employ to solve different problems. This usually happens at the end of a task where learners think back on the steps they took and become aware of how their own conceptualisation changed during the earlier part of the lesson.

In order to appreciate the methodology and philosophy of CASE it may be useful to compare CASE against characteristics of instructional teaching. Table 1 below shows some ways in which the two are different. Both offer outcomes that are unique and valuable in terms of the learning experience.

Table 1: Comparison of CASE approach and high quality instructional teaching

CASE approach	**Instructional teaching**
Lesson follows direction of argument	Lesson is carefully ordered and planned
Virtual objectives set	Specific objectives set
Students are often confused/ puzzled	Information is sizable and re-enforced
No/ limited content is delivered	Lots of content delivered
No obvious notes taken by students	Students have notes to review/ revise
No specific outcomes for the group of students	Very specific outcomes from lesson

In Box 2, the PST activity is presented. As with all of the activities in this Chapter it is envisioned that PSTs will experience the learning task as learners so that they can reflect on it and more effectively adopt it into their practice.

It is intended that through this example, PSTs will:

- Develop an understanding of the three pillars of CASE
- Enhance their own learning of the chemistry topic being taught
- Reflect on their own learning strategies used during the task and discuss the role of social collaboration in the development of their understanding of the concepts
- Critically reflect on their experience and through discussion with facilitators further explore how CASE could be translated into a classroom situation

It is noted that CASE methodology is complex and one experience won't fully prepare PSTs to use or understand this approach. If teacher educators are interested in using CASE they are recommended to read the following publication: Adey & Shayer, 1994.

Box 2: Outline of PST activity to introduce them to CASE

One example from CASE materials, *Thinking Science* (adapted from Adey, Shayer & Yates, 2001)

Lesson 23 "Explaining states of matter"

Step 1. PSTs observe stearic acid being heated (*cognitive conflict*). They discuss their observations in groups (*social construction*). They are provided with a list of words to help them describe their observations: melt, boil, freeze, gas, solid, liquid, condense, evaporate, solidify.

Step 2. PST (in groups) heat up other substances (ice, wax, lead, sulphur, iodine (demonstration only), and they record their observations for each one (*cognitive conflict*).

Step 3. PSTs are given some questions and activities to complete (*social construction*):

- You saw each substance in three different forms. What are they?
- Can you think of a way that all of the substances are made up, that would explain how they can melt and boil, condense and solidify?
- Write a story and/or draw pictures (in groups) to *explain* how substances can change from solids to liquids, from liquids to gases and back again.

Note: The 'explanation' part is really the whole point of the exercise, and yet one cannot prescribe how to manage it. [Give out poster paper and/or overhead transparencies. Encourage creativity.] If PSTs have already met particles, they may suggest this as an explanation but usually they cannot go on to explain how thinking about a particle model explains melting, boiling, condensing, solidifying etc. so facilitators should be prepared to push them to do more than just say 'particles'.

We simply want them to struggle with the idea of looking for an explanation, whatever they come up with. Facilitators should not suggest particle theory if it does not arise anyway. They should be 'non-directive' in discussing ideas, accepting virtually anything, but asking questions and pushing their models a bit.

Step 4: PSTs are asked to reflect individually on the learning experience. This should specifically focus on their thinking processes during the activity (*Metacognition*). Examples of questions in this pillar include: how did you find the solutions? how did you decide what to do at particular points? did you change your mind at any stage? what changed your mind? what idea(s) helped you solve the problem? could you use these ideas in other topics?

Step 5: Whole class discussion is held to consider the merits of this learning task design and how it could be adopted into a school classroom scenario

Good Practice Example 3: Using criteria-based peer assessment through modelling to assess understanding of chemistry phenomena

In the theoretical framework it has been noted that peer-assessment is an important feature of formative assessment. In Example 1 (Step 2) we have already seen one approach to its use where PSTs compared their concept maps. It is beneficial for PSTs to examine peers work and experience commenting on it or even grading it based on provided criteria. A further extension is to provide PSTs opportunities where they develop the grading criteria to be used. During both of these processes PSTs learn to appreciate what constitutes quality work and they can further use this to self-assess their own learning and progress.

Modelling has been selected as a teaching strategy to highlight the entwined nature of assessment and learning previously discussed. Modelling is an effective approach to elicit and develop learners' conceptual understanding of real word phenomena. Indeed, in Example 2 (Step 3) we have already seen one variation of modelling where PSTs were asked to draw pictures to explain/model their observations. The process of modelling involves learners constructing and refining models that explain their understanding of scientific phenomena. An advantage of using modelling in an assessment context is that it readily allows for teacher- and peer-formative assessment to be used to develop learning. A detailed analysis of effective use of modelling is beyond the scope of this chapter (refer to reviews such as Windschitl & Thompson, 2013).

It must be noted that a model is more than a simple representation of a system or a phenomenon. Modelling in this context refers to the process of constructing, evaluating and revising models. The use of modelling can help teachers 'see' student ideas, how they pull together different ideas and monitor development of conceptual understanding. Models allow teachers to work with student ideas, building on their understanding. The goal of modelling is not to produce the 'right answer' or the textbook explanation, but to represent science ideas.

Conceptual understanding of chemistry can be challenging to both teach and learn. Much of what needs to be understood in chemistry is unobservable and requires explanations and learning to be conducted at a microscopic abstract level. Often however, concepts can be described using unrelated surface representations thus students may not develop an atomic vision of the world that is essential for understanding chemistry. In this example, the concept of changing states of matter is used to highlight to PSTs the importance of developing their students' ability to negotiate learning of new chemistry concepts at a sub-microscopic level. The use of modelling in tandem with this topic is appropriate as students are encouraged to create pictorial explanatory models of the observable and unobservable aspects of the phenomena presented, hence providing an opportunity to develop their own abstract understanding.

This task (Box 3) is developed to enhance PSTs awareness of the benefits of using criteria-based assessment and modelling as a tool for developing students' understanding of chemistry concepts.

By the end of the activity PSTs should be able to:

- Develop assessment criteria for a range of learning activities (content knowledge, process skills etc.)
- Describe how modelling can be used as a tool to elicit and build upon students' thinking and learning
- Explain the importance of enhancing students' ability to examine chemistry concepts at an atomic level
- Critically reflect on the completed tasks and identify how the strategies experienced could be translated into a classroom situation.

Models are particularly useful in this topic of *conservation of matter* as many students and sometimes PSTs struggle with this concept. In discussions, the models should clearly reflect the following:

- State of substances at various temperatures
- Conservation of atoms in the example provided i.e. before, during and after changing state of matter
- Particle energy of different states at the same and different temperatures.

This activity can be used to develop criteria based assessment but also in the use of models in designing teaching and learning sequences. This task can pull together ideas that can be used together to inform the development of the model and particularly to see how the model changes with time.

In step two of the activity, it's suggested that PSTs generate a list of criteria to identify qualities required for a good explanatory model. Each time you use this activity PSTs will highlight different criteria, while there is no exhaustive list of criteria, Windschitl & Thompson (2013) provide a list of five key criteria, which are an excellent starting place to build from:

1) The model should represent an event or process rather than things such as text book representations
2) The phenomenon in the model should be set in a specific context (place, time, conditions etc.)
3) Diagrams and pictures help to make links between the phenomena and representations of the event or process being modelled
4) Models should include observable and unobservable features
5) Models need to be revisable.

Through experiencing the activity PSTs will learn how teachers can work with students to construct meaningful explanations that can be communicated in different forms to others. They will also see how students when completing a similar task are evaluating models, constructing meaning and developing their own self confidence as teachers to elicit student thinking.

Box 3: PST activity to introduce criteria based peer assessment through modelling (Conservation of matter / changing state)

Step 1: (Session One) PSTs are divided into groups. Each group is given a photograph of an example of changing states of matter e.g. burning coal fire, water evaporating from a kettle and melting ice caps. Each group is tasked to create an initial explanatory model of the phenomenon they've been given. These examples are chosen as they are about phenomena (rather than things), yet are specific but change with time and include both observable and non-observable phenomena.

Step 2: PSTs exchange their initial models with other groups. They are asked to make written comments on their colleague's model noting areas where it could be improved. The facilitator conducts a whole-class discussion to collate the nature of comments made and through agreement, uses this to generate a list of criteria to identify qualities required for a good explanatory model. A scheme for feedback or grading is then produced.

Step 3: (Homework Task) PSTs refine their models based on generated criteria.

Step 4: (Session Two) In this session PSTs comment on each other's models using the criteria generated from the first session and can give feedback or grade. The facilitator then uses a mix of group and whole-class discussions to guide the PSTs through a reflective process analysing the learning and assessment sequence they've experienced. During these discussions they highlight aspects such as:

- Role of the facilitator and learners at the various stages of the activity;
- Discuss the advantages and disadvantages of receiving comments on their work initially as opposed to being given a grade;
- Experience of refining their model based on agreed criteria;
- Nature of assessment used during the different stages of the activity;
- Using models as a tool to develop conceptual understanding;
- Understanding of states of matter;
- Challenges of teaching and learning abstract concepts.

Step 5: (Homework Task) PSTs are tasked with writing a reflection on the experience of generating criteria, using the criteria to refine their work and using models for teaching science. Additionally, they are asked to design a learning sequence that shows how aspects of this workshop could be translated to teaching science in a classroom situation.

Good Practice Example 4: Examining student discourse to assess conceptual understanding

In designing learning and assessment tasks, PSTs need to be fully aware and plan for the use of classroom discourse to formatively assess students' learning. They need to recognise the importance of embedding opportunities for classroom discourse in their practice and to examine questioning and discourse strategies that foster student talk.

Discourse is one strategy that is beneficial in providing students opportunities to put forward their ideas and to discuss and challenge each other on scientific issues. In this regard discourse supports students to reason about science concepts, observations and evidence.

Looking back at chapter "Educational Theories and How Students Learn Chemistry: Practice what you Preach", it was noted how students construct understanding and how social construction plays a key role in this perspective on learning. Discourse is at the heart of strategies that follow a constructivist standpoint. Articulation of ideas through talking helps students formulate their knowledge as it forces them to think about their conceptions. It also lets them share their knowledge with peers so that their current understanding become a source that can be used by the group to co-construct their conceptual understanding. Furthermore, discourse is useful for teachers to assess students learning. Given that student talk is a representation of their thinking, encouraging them to converse is one way of making their thinking visible.

The quality of and frequency of student talk is fundamental to the success of developing and assessing learning. Unfortunately, discourse in classrooms tends to be dominated by the teacher acting in an authoritative position, who directs when students can and can't talk (Cohen, Manion and Morrison, 2004). Encouraging the use of discussion and discourse is challenging and issues around its use are multifaceted. Newton, Driver and Osborne (2004) highlight several barriers raised by stakeholders that limit the use of discussion in classrooms including time, amount of curriculum content, managerial issues, teacher confidence, and perceptions and models of learning science. The latter issue is interesting in as far as it's shown that teachers' beliefs around how science is learned has an influence of the nature of talk in their classrooms. These beliefs are difficult to change, as teachers are encultered by their own learning experiences, which are often centred on transmission strategies. It thus becomes the responsibility of teacher educators to demonstrate the merits of using discourse (supporting a social constructivist perspective of learning) and support PSTs to develop the skills (facilitation, effective questioning etc.) required to use the pedagogy in their practice. The activity outlined below is a starting place to tackle this challenge.

Box 4 outlines the approach used in PST discourse activity, while Box 5 is an example of a Vignette of Classroom Dialogue that was used for this activity. Box 6 outlines some of the starting points for the discussion on the analysis of the dialogue. This section gives ideas for the discussion and PSTs with their educators will add more points than noted here. On completion of the activity PSTs should be able to:

- Analyse transcripts of classroom discourse to assess student conceptual understanding
- Analyse transcripts of classroom discourse to identify opportunities to assess student conceptual understanding

- Outline and describe teacher strategies that encourage effective discourse in a classroom setting
- Describe how discourse can be used as an effective learning and assessment strategy to build and elicit students conceptual understanding

Box 4: PST activity on assessing conceptual understanding through discourse

Step 1: PSTs are given a vignette of classroom discourse (Box 5). They are asked to (individually) read it and identify students' conceptions of the chemistry topic being discussed and note their evidence for making this judgement. When completed they are divided into groups and asked to compare their responses. This is followed by a classroom discussion particularly focused on the evidence they used to evaluate students' conceptions

Step 2: PSTs are asked to complete a think-pair-share activity where they answer the following questions on the vignette provided:

1) Critique the teachers questioning regarding its success in eliciting student ideas and cognitive demand (higher order, lower order etc.)
2) Identify opportunities where student conceptions could have been probed further
3) Make a list of questions the teacher could have used to elicit student ideas
4) How can students be encouraged to use scientific language during classroom exchanges
5) How can students be encouraged to base with their contributions on evidence and not opinions

Step 3: PSTs engage in whole class discussion on the importance of encouraging student discourse in the classroom and how it is beneficial in eliciting student understanding.

Step 4: Based on the vignette provided and the follow on discussions (Steps 1-3), PSTs are asked to design a learning task that will address the misconceptions or questions identified.

Note: In Box 6, some key points that should be addressed are highlighted

Box 5: Vignette of Classroom Dialogue

In this example a teacher is introducing the concept of pH and pH curves. The students have encountered acids and bases in lessons in a previous year in which they examined the properties of acids and bases, looked at everyday examples and related those to a position on the pH scale.

Dialogue 1: **Eliciting prior knowledge**

This class starts with a refresher of what was covered previously. The teacher develops a concept map to ascertain students' prior knowledge and to help them to recall their knowledge so they can prepare for the activities in this class.

[Teacher] *What can you remember about acids and bases from what you learned previously?*

[Jack] *They're sour tasting*

[Teacher] *What are, Jack?*

[Jack] *Acids, they're sour. They dissolve things quickly and they burn through things*

[Teacher] *Thanks Jack* (Teacher notes Jacks comments on the board)

[Melissa] *Does pH have something to do with it?*

[Teacher] *Thanks Melissa, Yes*, (He notes it on the map). *Sarah can you add any more ideas?*

[Sarah] *Yeah, we looked at different examples of acids and bases, so like, acid rain, vinegar and your stomach would be acids and drain cleaner, toothpaste and soap would be bases. I think bases are sticky or thicker liquids compared to acids.*

[Teacher] *Ok, Sarah some good examples there, we'll add them to our map. Peter, going back to Melissa's point about pH scale, can you say anything more on that?*

[Peter] *Sure, it goes up to 14 and 7 means things are neutral.*

[Teacher] *Right, where are the alkali and acidic parts of the scale?*

[Peter] *Below neutral, things are acids and above it they're bases*

[Teacher] *Good Peter*, (He adds to the concept map). *Alright thanks, Ok so I'm going to write a list of chemicals on the board and in your pairs I want you to list which ones are acids and bases.*

Teacher puts up a list of acids and bases on the board including HCl, H_2SO_4, HNO_3, LiOH, NaOH, $Ca(OH)_2$, $Mg(OH)_2$. In pairs the students sort them into acids and bases.

[Teacher] *So Jane, what have you and Peter come up with? Which are the acids?*

[Jane] *We said that HCl, H_2SO_4 and HNO_3 were acids*

[Teacher] *Ok,* (he notes this on the board) *Does everyone agree with this? Jack, what about you and Sarah, do you agree?*

[Jack] *Yes*

[Teacher] *Ok, Melissa you were working with Paul right? What bases did you pick out?*

[Melissa] *Hmm, we weren't sure about HNO_3 so we left that out but we said all of the remaining ones were bases.*

[Teacher] Adds Melissa's note on the board. *Ok, so we've sorted them into acids and bases correctly, but why did you choose this categorisation? What pattern do we see?*

[Sarah] *All of the acids have Hydrogen in them?*

[Teacher] *Ok, Sarah are there Hydrogen's in the bases too?*

[Sarah] *No that's different that's bonded to the oxygen so it's like an OH something*

[Teacher] *Ok Sarah, I think what you're saying is that in the acids we have a H^+ ion and in the bases we have an OH^- ion released when they're in solution*

[Sarah] *Yeah ions*

Dialogue 2: Discussing the pH scale and Predicting shape of pH curve

The teacher finishes off his initial eliciting of students previous knowledge and starts the next part of the class. He introduces the idea of quantitatively measuring pH.

He explains the practical activity that students will complete in pairs. They are tasked with carrying out a neutralisation reaction where they will react HCl and NaOH. They are requested to monitor the pH using phenolphthalein indicator and a pH probe connected to a data logger, which produces a live graph. Before they start, the students are asked to work in pairs to predict what the graph will look like. They draw their graphs on mini-white boards and raise them so everyone can see.

[Teacher] *Ok so lets get some of your ideas, hmm we've got a few different looking graphs. Lets start with you Jane, can you explain your graph to the class.*

[Jane] *Peter and I think that the reaction is a 1:1 ratio so we drew a linear graph*

[Teacher] *Ok, so where does your graph start and where does it go to?*

[Jane] *Well it starts at around 2, shouldn't it? it's an acid right?*

[Teacher] *Yes, HCl is an acid*

[Jane] *Yeah, so yeah it starts there and goes to 14 because NaOH is a strong base and it'll end up an alkaline solution*

[Jack] *Our graph is different, we went with a curve, I was thinking it was going to be a straight one first but Sarah pointed out that you're only adding in the base little by little so it'll take ages for it to have an effect so it'll be an acid first and then it'll shoot up when it's getting neutralised, right?*

[Teacher] *Ok, so Jack, what happens after neutralisation*

[Jack] *It'll just be the opposite, it'll be fast and then level off when it hits pH14*

[Paul] *Now I'm confused, we had a straight line too, we thought that it can only react with one molecule at a time so it doesn't really matter if there is more or less of the bass, I'm not so sure now, I can't visualise it.*

[Sarah] *It can't be straight, what Jack said is right. I'm not fully sure how steep the curve is but it has to have a long flat bit at the top and bottom because at the start we'll have excess acid and at the end there will be excess base. I think the neutralisation will happen fast, kind of like a tipping point as there's only going to be a little acid to neutralise at the end.*

[Teacher] *Ok, we'll come back to the shape later after the experiment, what about the start, I notice Sarah that your graph starts at 0 and everyone else's starts at 2. Can you comment on that?*

Sarah] *We just figured that HCl is a strong acid so it's got a really low pH, I think it's 0 in the book*

[Teacher] *Ok, so just remind us what pH is measuring?*

[Sarah] *How strong an acid is, the amount of Hydrogen's it gives off*

[Teacher] *Yes, it's the concentration of the Hydrogen's that's important and you're correct strong acids will have more Hydrogen ions in solution. Ok, lets leave it there, we have a few ideas that we need to explore in our experiment and we can chat about them further later.*

Dialogue 3: Discussion of experimental findings and concept models

The students complete the experiment and share their findings. All students obtained the same pH curve. The teacher arranges the class in six groups of four students. He asks them to trace their graphs into their copies and annotate them with three diagrams, which model what's happening inside the reaction vessel (1) at the start, (2) at the neutralisation point and (3) at the end of the reaction. The teacher circulates around the groups and discusses their models. The first group includes Jack, Sarah, Peter and Jane.

[Teacher] *Ok so we've seen the graph has a shape that is more like the curve that Jack and Sarah proposed and we linked this to amount of the acid and base so how are you representing that at a molecular level.*

[Peter] *At the start it's all acid so we've drawn a lot of* H^+ *and* Cl^- *ions in the solution because it dissociates readily as it's a strong acid*

[Teacher] *I get that, so what happens at neutralisation? Jack, at pH7 the number of* H^+ *and* OH^- *will be the same, won't they?*

[Jack] *Yes*

[Teacher] *So after that we're still adding* OH^- *aren't we?*

[Jack] *Yes*

[Teacher] *That'll neutralise the H+ won't it?*

[Jack] *Mmm, yeah,*

[Teacher] *Good you've got it. Now Jane, What happens when the curve starts to change shape after neutralisation? Can you explain it? What happens just after, will it have a small amount of base, equal amount or will there be lots more?*

[Jane] *There'll be a little bit of base*

[Teacher] *Great, well done!*

Box 6: Getting started with the analysis

A lot of discussion can be generated from this dialogue particularly during Step 2 and Step 4 of the activity. A few things are noted below to help you get started with the activity.

- The teacher was haphazard when trying to elicit student ideas, sometimes he pressed for deeper understanding and at other times, he didn't challenge students to explain or justify their answers with evidence, e.g. when questioning Jack in Dialogue 3, the teacher used closed questions that only required yes/no answers
- Some students don't appear to fully understand what the pH scale measures, 'strength of an acid' and 'acidity of a solution' appear to be used interchangeably e.g. in Dialogue 2 Sarah seems confused about what the pH scale measures
- Sometimes the teacher paraphrases students answers and adds scientific terms to help their literacy e.g. in Dialogue 1, the teacher introduces the term 'ion'

- Possible questions the teacher could have used include: Is pH constant? Is the pH of HCl always pH1 or can it change? What is the difference between a strong acid and a concentrated acid? How is this identified on the pH scale? Can a solution containing a 'weak acid' and a solution of a 'strong acid' measure the same pH? How could we determine the relative 'strengths' of acids using the pH scale?
- A possible follow on activity could be to ask students to do serial dilutions on 1M HCl and measure its pH at different concentrations.

Conclusions

In this chapter, the need for designing good quality learning and assessment tasks has been highlighted. Learning and assessment are fundamentally entwined and so four approaches highlighting different aspects that can help PSTs to broaden their skill sets are presented in this chapter. Each of the examples given can be used to support the PSTs' development of their own knowledge of chemistry and also can be used by teacher educators in the assessment of the PST.

The concept map as a technique to draw together and consolidate both their understanding of chemistry concepts and also how to link and develop concepts was given in Example 1. The CASE example given in Example 2, highlights the importance of building on students' own ideas and so the PSTs have an opportunity within this example to examine the language used in social construction and the power of that within their lesson. Building of models is important in a subject as Chemistry as it is important to present their ideas. Frequently, mental models differ between individuals and it is important to use the power of modelling to elicit ideas. Finally, in the design of learning and assessment tasks, PSTs need to be aware of the power of discourse. By examining vignettes of teacher-student dialogue, PSTs will be more aware of building it into their planning process and also of providing opportunities for assessment for learning.

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