Designing Effective Science Instruction

What Works in Science Classrooms

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Revised Australian Edition
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Contents

Introduction

Why This? Why Now?

Science teachers, like all teachers, start each school year with high hopes and expectations for students to succeed. They plan their lessons, scramble to get the necessary equipment and work hard to engage their students. However, despite good intentions and best-laid plans, not all students do well in science classes and even fewer achieve mastery. We see the effects of this all around us. Results from international student assessments show that the scores achieved by Australian students in both mathematics and science have largely stagnated over the last 16 years (ACER 2014). Australia's scores display a substantial 'tail' of underachievement, with only a modest proportion of students satisfying high and advanced benchmarks. More and more adults are unable to understand the scientific issues that affect their lives and society, yet a recent survey on science literacy published by the Australian Academy of Science (Wyatt & Stolper 2013) found that most people view science education as very important to the Australian economy. It's clear that something must be done to help science teachers make their hopes and expectations for student achievement a reality.

Designing Effective Science Instruction: What Works in Science Classrooms is meant to help teachers focus on what can and must be done. It draws upon recent research into student learning and describes how best to incorporate the recommendations of that research into our science teaching. Teachers are often unaware that there is an increasing body of research identifying the teacher knowledge and skills that significantly enhance student learning. We believe that designing high-quality science lessons that include these research-based instructional practices is a logical first step to improving all students' science learning. As a result, *Designing Effective Science Instruction* focuses on strategies that science teachers at all levels can use to make their science lessons more effective.

Educational research on learning and effective science instruction has much to offer us in meeting the challenges of educating students to high standards. What do that, we have appended to this chapter three C-U-E self-assessment tools (pp. 195–197) that will prompt you to think about the strategies you currently use to support students' acquisition of significant content, develop student understanding and create a climate conducive to learning. The checklists will help you to capture where you are at this moment and to identify areas you would like to work on or learn more about.

The C-U-E Framework

The three elements of content, understanding and environment are equally essential to improving student learning. A weakness in any one will undermine the effectiveness of the other two. We designate Content as the first element of the framework to underscore the idea that designing effective science lessons can only occur when we are clear about the big conceptual understandings and key concepts that will be included in the unit. Identifying the significant, worthwhile content also helps us to begin thinking about how to sequence lessons as part of a coherent science unit and a coherent science program. We should think first about content at the course of study or year level and then at the individual unit of study level. Creating that big picture and identifying the big ideas within a course or year level are necessary steps before going to the smaller grain size of individual lessons.

Teachers have expressed two major concerns with regard to content: insufficient time for students to develop conceptual understanding and too much content to cover to prepare students for major assessments. Further, since implementation began in 2011, aligning school curricula and assessments to the new Australian Curriculum: Science has been another challenge teachers must face. To address time and coverage issues, we need tools and clear procedures to identify all of the content embedded in Australian Curriculum: Science content descriptions and achievement standards. This 'unpacking' of descriptions and standards helps us to ensure that we focus instruction on the important learning objectives. Using lesson and unit templates helps us address alignment issues.

Since our focus is clearly on designing effective science lessons with effective science instruction to deliver those lessons, we also talk about some of the features of ineffective practices at the same time that we are recommending effective strategies. Some of these ineffective practices are obvious, such as teaching lessons as if students were empty containers to be filled with science knowledge that we tell them, sometimes over and over again. We also want to guard against treating students as passive learners – learning is something students have to do themselves.

In the remaining sections of this chapter, we introduce the recommended strategies for each component of the framework. Chapters 2, 3 and 4 provide details and tools related to the recommended strategies.

Identifying Important Content

When we talk about identifying important content, we mean starting unit planning and then lesson planning with clarity about the knowledge students should acquire – the information and ideas they should understand and the skills and processes they should be able to perform. Planning also includes identifying the criteria for successful demonstration of learning and deciding how students will demonstrate the required content knowledge. Once the big ideas and key concepts are clearly identified, we can identify specific learning targets as we plan activities that are sharply focused on helping students achieve conceptual understanding and procedural fluency. Intellectually engaging students with the content means that we need to include relevant, emerging content (e.g. plasma state of matter, genetic

Table 1.2
Identifying Important Content

<table>
<tr><td>Strategy 1: Identifying Big Ideas and Key Concepts
Identify big ideas, key concepts, knowledge and skills that describe what the students will understand.</td><td rowspan="6">Why am I doing this?

What are the important concepts and scientific ideas included in the lesson?</td></tr>
<tr><td>Strategy 2: Unburdening the Curriculum
Prune extraneous subtopics, technical vocabulary and wasteful repetition.</td></tr>
<tr><td>Strategy 3: Engaging Students with Content
Create essential questions that engage students with the content.</td></tr>
<tr><td>Strategy 4: Identifying Preconceptions and Prior Knowledge
Identify common preconceptions and prior student knowledge.</td></tr>
<tr><td>Strategy 5: Developing Assessments: How Do You Know That They Learned?
Develop assessments that correlate to the conceptual understanding and related knowledge and skills.</td></tr>
<tr><td>Strategy 6: Sequencing the Learning Targets into a Progression
Clarify and sequence the learning targets into progressions to focus instruction on building conceptual understanding. Align learning activities with learning targets.</td></tr>
</table>

5. The sun's gravitational pull holds the Earth and other planets in their orbits, just as the planets' gravitational pull keeps their moons in orbit around them. (KC 3)
6. How we understand the movement of celestial bodies has changed as a result of new scientific observations. (KC 3)

We can now begin to map a curriculum unit outline that can be shared with students and parents, similar to the partially completed example presented in Figure 2.2.

The final steps in developing an outline are to identify what students should be able to do to demonstrate their learning and then list the essential vocabulary for the unit. Figure 2.3 (p. 28) shows another example of a curriculum outline, this time for a Year 10 unit on the periodic table. It covers content description ACSSU186:

> The atomic structure and properties of elements are used to organise them in the Periodic Table (ACSSU186)

For this unit, the big idea is: *The chemical and physical properties of an element are determined by its atomic structure*. The completed unit outline in Figure 2.3 shows the big idea, key concepts, associated learning targets, success criteria and essential vocabulary.

Planning for Classroom Implementation

As we think about using this strategy in our classrooms, keep in mind that big ideas represent the central principles of the science disciplines and encapsulate the concepts embedded in our science curriculum. Our first task is to identify the big ideas at the overall course or year level. This helps us to connect the goals for student learning into a systematic framework. After identifying the big idea for each unit, we must identify the key concepts, facts and vocabulary that are embedded in the big idea. Although this might seem like a lot of work, organising teaching around big ideas provides coherence to the curriculum. It also helps us align the curriculum with student learning so that what students should know and be able to do directly relates to the learning goals.

To uncover the big ideas, key concepts and vocabulary for your own unit of study, go back to the steps involved in the process. Use the resources mentioned as well as online resources. A sample unit planning template is provided in the appendix for Content Strategy 1 (pp. 202) for you to record the big ideas and key concepts for your unit of study.

Figure 2.2
Sample Unit Outline Aligned to the Australian Curriculum: Science for Year 7

Unit Title: Gravitational Forces	Year: 7	Area: Physical Science
Australian Curriculum Content Description Earth's gravity pulls objects towards the centre of the Earth (ACSSU118)		
Big Idea Gravity is a force of attraction between two objects that acts in predictable ways.		
Key Concepts Gravity is a force of attraction between any two objects that have mass. (LT 1) Gravity acts at a distance, not through contact. (LT 2–3) Gravitational force between celestial bodies results in the orbital motion observed in space. (LT 4–6)		
Learning Targets Students should know and understand that 1. Every object exerts gravitational pull on every other object. The force depends on how much mass the objects have and how far apart they are. The force is hard to detect unless at least one of the objects has a lot of mass. 2. Anything on or near the Earth is pulled towards the centre of the Earth by gravitational force. 3. Weight changes according to the size of the gravitational force applied to a mass. Mass is a measurement of inertia. 4. There are many types of celestial orbits, depending on the relative size, distance and motion of the objects. 5. The sun's gravitational pull holds the Earth and other planets in their orbits, just as the planets' gravitational pull keeps their moons in orbit around them. 6. How we understand the movement of celestial bodies has changed as a result of new scientific observations.	**Success Criteria**	

What Works in Science Classrooms: Implications for Teaching

Recommendation 1: Students learn concepts better when they experience something by engaging in an inquiry rather than reading about it or hearing a lecture. When students work like scientists, they use language to organise, recognise and internalise the concepts and information they encounter. Because students ask questions and discuss their results, inquiry activities help students engage in explanatory talk that promotes understanding.

Recommendation 2: In a unit of study, you should choose those concepts that are difficult for students to understand and teach them using inquiry instruction. This way we can involve students in scientific questions, completing an investigation that connects to their existing ideas, answering the question and presenting and discussing their results with others. Through observation, manipulation of variables and discussion of results, students will reveal their thinking, make sense of the learning and develop conceptual understanding that can be applied to new learning experiences.

Understanding Strategy 2: Implementing Formative Assessments

The Issue

Students learn at different rates and bring different background understanding with them to class. As a result, the learning gaps between where students are and where we want them to be differ. The problem is our lessons don't usually take this into account. Teachers plan lessons that are not based on where students are relative to the learning goal, and most lessons are taught assuming that students start with basically the same background. Teachers also don't take the time to determine the progress of student learning while instruction is still on going.

The DESI Approach

We recommend implementing formative assessment processes that provide the teacher with feedback about student understanding. Taking this feedback into account, we can adjust our teaching program and plan for additional learning experiences that meet our students' needs. Formative assessment of student learning can be incorporated into any lesson but should be included after teaching a concept. Formative assessments can be used before instruction (to determine

Table 4.2
Analysing Teacher Beliefs and Actions That Support a Climate of Learning

Scenarios	Teacher Belief	Impact on Learning	Recommendation
1. Homework	The teacher believes that homework every day will develop good study habits among the students.	Since the students are assigned homework every night, it is having a negative effect on their willingness to use homework to improve learning. This negatively impacts all students.	Not all homework is the same and some homework is for practice and some is for preparation or elaboration (Marzano, Pickering & Pollack 2001). Homework should only be assigned periodically and should be commented on to improve the effect on student learning. Create a homework policy.
2. Marking	The teacher believes that dropping the two lowest scores is fair for students and solves the problem of students with low scores or zeros.	The two lowest scores may represent significant assessments of student achievement. The low-achieving students are affected by receiving marks that do not adequately align with learning and instead result in mark inflation.	If receiving evidence of student learning is the goal, then devising a strategy that allows for extended time to complete work will maintain rigour and still accommodate personal student issues. Try providing two 'oops' passes each marking period to extend deadlines.
3. Classroom Expectations	The teacher believes that they create a positive classroom climate by being the students' friend and sharing personal information.	Students may not be clear about classroom expectations. Trying to be a friend affects all students because the focus is not on a well-managed or learner-centred classroom.	Establishing clear classroom expectations provides order for all students. Providing procedures for students creates a sense of comfort that supports all students. Time spent on telling a personal teacher story is time away from instruction.

To help foster a positive school culture, administrators need to encourage a growth mindset among teachers, and teachers should do the same with students. The climate within the school should reflect the belief that intelligence is fluid and that the goal is to help everyone get smarter. By its actions, the school needs to show that it values (and praises) taking on challenge, exerting effort and overcoming obstacles more than it values (and praises) 'natural' talent and easy success – that it believes 'the harder I work, the smarter I become'.

Appendix Chapter 1.
Lesson Design Framework

Lesson: ____________________
Evaluator: ____________________ **Date:** __________

1. Make notes of the strengths and weaknesses of this lesson.
2. Use your notes to prepare a summary and specific recommendations for improvement of the lesson design.
3. Keep in mind that our goal is to improve student understanding of important content.

1. **Big idea, key concepts, knowledge and skills** are described in terms of student understanding ➔ are accurate ➔ don't reinforce misconceptions
2. **Summative assessment** provides evidence of learning ➔ has to relate back to key concept ➔ students can demonstrate high cognitive ability when demonstrating conceptual understanding
3. **Essential questions or activities** engage students in the content and motivate them to learn ➔ may be a discrepant event ➔ should be age appropriate
4. **Students' prior knowledge** is acknowledged and built upon ➔ background info on the concept for teachers ➔ what are the prerequisite student learnings? ➔ how do we know what the students know (drawing, prediction, response to essential question …) ? ➔ what are the common preconceptions?
5. **Formative assessments** measure progress towards student understanding and inform instruction ➔ include a variety of opportunities ➔ give example and invite teachers to create their own