Movement and force
by Russell Tytler, Linda Darby and Suzanne Peterson

Introduction
How – and why – do things move? How do we describe how they move? This chapter looks at ideas and activities concerning movement and force. It deals with two major issues: firstly, ideas children have about motion and the strategies for teaching about motion in the primary school program. This will include some discussion of the different contexts in which movement and force can be studied. Secondly, it looks at the wider context of studying movement and force, linking it with technology and science as a human endeavour.

Background to the chapter
Two of the authors (Russell and Suzanne) were involved in a longitudinal study of children’s science learning and, as part of that, have explored, through activities and interviews, ideas about movement and force and air and flight. Some of the material in this chapter relates to the insights generated from this exploration. Another specific input into the chapter comes from work that Linda has been undertaking with her science teacher education students around literacy and unit design based on the Primary Connections 5E framework. Other activities, in particular the unit sequence, derive from work that Suzanne conducted with her own years 3 to 4 class. Some of the wheels and language activities are based on the ideas of Tom Radford, who was an earlier contributor to this chapter.
Thinking about movement and force
What makes things move? How do they slow down and stop? How do forces come into this? Below is an activity sequence that might be used to introduce ideas about movement and force. Think about what your own response to the activities might be – even try the activity out and think about variations!

An activity sequence to elicit and challenge children’s ideas

**Push and pull**
Start with a toy that moves. What do you do with it? Which toys do you push and which toys do you pull?
  Using butcher’s paper, create a list of things that you push, things that you pull.

**Acting on playdough**
Children are given playdough and asked to say what they might do with it. In small groups, they explore with the playdough.
  Gather them back together to talk about the different things they did: twist it, squeeze it (squeeze is two pushes – one from each side), press it. Introduce diagrams, with arrows as a visual symbol to represent pushing and pulling. Ask children to draw what they did to the playdough.
  Establish, through discussion, the effectiveness of diagrams and arrows to represent/communicate what is happening – a lower secondary school teaching sequence based on this idea is described in Hubber, Tytler and Haslam (2010).
  Challenge the children to think about what is happening when they squeeze an aluminium can, sit on a sponge cushion or squeeze a toothpaste tube.

**Pushing and pulling a table**
Up-end a table onto the floor. Challenge children to pull it. What happens if someone stands on it? What happens if two people stand on it? What difference does it make if two people both pull? What happens if one person pulls and the other pushes from the other end?
  Loop an elastic length (such as stockings) around the table and investigate how much force is needed by one person, two people etc. to pull the table.

<table>
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<th>Activity 3.1 Representing force</th>
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<td>1. Discuss with friends what view of force is being encouraged by the sequence above.</td>
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<td>2. Note that in each case the force is represented as coming from an outside agency – a hand, a rope. Is this always true of force?</td>
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<td>3. Discuss the way the sequence builds multimodal representations of forces acting on objects, including body–kinaesthetic, verbal, and visual/symbolic.</td>
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<td>4. Think about and sketch, using arrows to represent forces, the forces acting on a</td>
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Scientists’ ideas about movement and force

The theory of movement we accept as the official scientific view was largely developed by Isaac Newton in the 17th century. Newton argued that we should think of force as causing changes in motion rather than motion itself. Forces are the way we describe the effect of external influences on an object. An internal force, such as gripping a steering wheel or pushing on the brake, will not directly slow your car down or otherwise affect its motion, but the friction on the car tyres from the ground will. Thus, a ball or a box, for instance, will move along a flat surface forever, unless an external force (such as friction or a kick from a boot) acts to stop it, speed it up or deflect it sideways. The box, if it is sitting on the ground, will experience a gravitational force down, balanced by a reaction force up of equal size. Thus, the total force on the box is zero. The reaction force is similar to the force acting on you if you stand on a trampoline as it is stretched. In fact, the ground will be ever so slightly stretched in the same way, much as a plank of wood or a wooden floor might be, so that it exerts a force upwards on you.

Forces do not always result from direct contact. Take the case of gravity. Newton showed that the weight force acting on an object is due to gravitational attraction from the Earth and that this force, which causes apples to fall, is also the force that keeps the moon orbiting the Earth. Let’s sum up a short list of scientific ideas about force before moving on to challenge and refine our views:

• Forces cause changes in motion and are not, unlike momentum and energy, associated with the motion itself.
• Forces are our way of describing the way external effects (pushes, pulls, gravity, support) can influence the motion of things.
• A force is an effect on an object, not a property of the object or its motion. If you want to explain a change in motion (speeding up, slowing down, swerving), then you must look for an external effect and not at the object or something inside it.
• Forces occur in action–reaction pairs. Thus, if your standing body pushes down on the ground, the ground will push back up on you.
• Pairs or sets of forces will add together to affect motion. But, as the addition must take into account direction, opposing forces can cancel each other out.
• Common forces include contact forces (physical pushes, support or traction from the ground, friction, air or water resistance opposing motion, force from wind) and field forces (gravity, magnetic forces, electric field forces).
Alternative conceptions about movement and force

Many studies of informal ideas about movement and force (for example, Gilbert and Watts 1985; Gunstone 1987; Ioannides and Vosniadou 2001) have shown the difficulty that children and adults have with the idea of force and the causes of movement. In fact, children’s ideas about force have been shown to have a lot in common with the ideas of earlier scientists, such as Aristotle and the medieval impetus theorists who thought of force, or ‘impetus’, as residing in moving objects (McCloskey 1983).

Gilbert and Watts (1985) identified a list of intuitive (and scientifically unacceptable) rules that children have been found to use in explaining motion. These are:
• Forces are to do with living things (things, such as gravity, friction or jet propulsion, are not forces, but people can apply force).
• Constant motion requires a constant force (rather than constant motion resulting from no force and a net force causing speeding up or slowing down or deflection).
• The amount of motion is proportional to the amount of force (faster-moving objects are thought to have or need a greater force, whereas, according to the scientific notion of force, an object, such as with a spacecraft, can be moving very fast even with no force on it).
• If an object is not moving there is no force acting on it, and if a body is moving there is a force acting on it in the direction of motion. (This is not true. For instance, there is no forward force on a rolling or sliding object – friction will act in a direction opposite to the motion. A stationary person standing in a room is subject to two forces, as discussed above.)

Further, there is a lot of evidence that children are of the view that force is a property of a body, a sort of power or energy within the body that stays with it but gradually diminishes as the body slows down. This idea has more in common with old ideas about impetus or the concept of momentum than with the scientific view of force. These ideas have been repeatedly identified in a range of studies. It has been argued (Stein, Larrabee and Barman 2008) that the identification of the extent of such beliefs through elicitation tasks can help teachers plan effective instruction.

A Victorian study (Adams, Doig and Rosier 1991) has examined students’ ideas in a range of science areas, including movement and force. A brief look at some of their findings for Year 5 students is instructive. You might like to think about how you would answer their questions (see Figure 3.1) yourself before reading the interpretations.

The skateboard rider stops kicking (see Figure 3.1). Why does the skateboard stop? Forty per cent of Year 5 students’ responses were uninterpretable and 48 per cent gave responses

![FIGURE 3.1 Probes of understanding about force](image)
implying that, without a kicking force, there is no motion. A further 4 per cent thought the rider supplied a force, energy or power to the skateboard, which stops when this is used up. In fact, the skateboard experiences a gravitation force down, a reaction force up from the ground and a frictional force that acts against the motion and slows the skateboard down. These cartoon probes can be used in class as elicitation techniques to promote discussion and rethinking of ideas about force.

Adams, Doig and Rosier (1991, p. 23) analysed the responses on all items and were able to divide Year 5 students’ views about motion into five levels along a continuum. All but 4 per cent of students had views substantially at odds with the scientific notion. Most had few or very confused ideas. At the upper end, the bulk of students were at a transitional stage in which they have some awareness of the scientific notion of force but retain elements of intuitive conceptions, such as the necessity of force for movement and the idea of force residing in an object. Students at this level may explain that a thrown ball is given a force by the thrower and that force now resides in the ball and keeps it moving.

Alonzo and Steedle (2009) used multiple-choice tests to develop and refine a Force and Motion Learning Progression that describes a sequence of conceptions of increasing sophistication, identifying common errors at each stage. Thus, at level 1, students understand force as a push or a pull, but may think that a force is caused by living things or is an internal property of a moving object. At level 2, students understand the links between force and motion, but may think that an initial force is carried with the object but may dissipate as it slows, or that if there is no motion there is no force. At level 3, students understand that an object will be at rest if there is no force or if there is no net force acting on it, but may think that objects will slow down naturally even without force, or that speed rather than acceleration is proportional to force such that an object will come to rest if forces are in balance. Such learning progressions are receiving increasing attention as ways of thinking about and planning for student learning.

It has been shown that children, even if they have learnt to use scientific ideas in school, often revert to their life–world beliefs when dealing with situations outside school. It is as if they think in two domains, one relating to the classroom and one to their out-of-school lives (Solomon 1983). The scientific concept of force is neither intuitive nor easy to grasp, but is important for interpreting many situations. Adults and children need support to clarify their understandings about gravity, friction and what we mean by force. Much of the teaching at primary school could concentrate on developing a more consistent language in which force and energy are distinguished.

A difficulty in building up a consistent, scientifically acceptable view of motion seems to be the influence of friction, which acts to slow things down and which is associated with the decrease of energy of motion and its conversion to heat energy. It is our common experience that things do stop when we stop pushing them. It takes a leap of imagination to be convinced that a brick would keep going steadily across a floor or field if it wasn’t for frictional effects. Compare, though, what would happen if the brick were slid across a skating rink, or think about how carefully you need to walk across an icy surface. Wheels have the effect of reducing the amount of friction because, with a wheel, the point of contact with the ground is not sliding, but is momentarily stationary. There is some friction from the ground,
However. The amount will depend on the surface (think of riding a bicycle in sand) and on factors such as how freely the wheel spins.

A British study of primary school teachers’ ideas about force (Kruger, Summers and Palacio 1990) showed similar conceptions to be held by adults. The difference in this case was that while the teachers showed considerable confusion, they were much more reflective about the state of their knowledge and were concerned about achieving a consistent view of motion. Some of their responses in ‘interviews about instances’ based on prompt cards are given below (Kruger and Summers 1988, pp. 6–10). They illustrate a range of informal views about motion.

**Instance 1:** A person is riding a bike. There are no brakes, he is not pedalling but is slowing down. Is there a force on the bike?

Yes, momentum [The force he exerted when he was pedalling] … that’s gone … almost stored in the system. Stored energy … a stored force …

[the force that was there when he was pedalling] hasn’t got really expended yet … it’s running down.

**Instance 2:** A golf ball has been hit and is now on its way down, falling freely to land on the green. Is there a force on the golf ball?

now it’s losing the force from him and its own weight’s going to make it start dropping and gravity … and air resistance this way.

Well, as it’s still going forward, I would have thought yes [the force of the hit is still with it] because if there were no force it would be dropping straight down …

I’m not sure whether once the thing has been set in motion, you discount … the impetus … there is in one sense a force that has been but whether you still talk about [it] once the actual work is finished [and it’s] set in motion, I don’t know … the weight … is vertically downwards but because the ball is already in motion the ball doesn’t go vertically, but that may not be anything to do with the force because the force is actually vertically downwards.

**Instance 3:** A box is pushed and then is sliding down a slope. Is there a force on the box?

Does friction come in? ... I don’t know if you call it a force ... because it stops ... if you think of skiers, they want minimum friction ... So it’s stopping it moving, it’s not a force.

In the student conception literature, the concepts associated with force and motion have received a lot of attention. Planinic et al. (2006) showed these naive conceptions to be particularly strong, not only in that students answered according to them, but also that the students had high levels of confidence in these naive beliefs. This was particularly true of the following conceptions:

- constant force produces constant velocity
- heavier bodies fall faster
- a body can be at rest while an unbalanced force (gravity) acts on it.

They hypothesised that the strength of these naive conceptions about force and motion comes from the fact that these are topics with which we have everyday and longstanding familiarity. Chi (2005), on the other hand, argues that conceptions such as ‘force is the property of a moving body’ are difficult to shift because they require a category change for force, from a property to an effect. Other naive conceptions, such as that an insect is not an animal, do not involve such a shift and therefore are not so robust.
Effective teaching about movement and force

The constructivist principles involved in teaching about movement and force are no different to those that might be used for any topic, but there are some special issues that have been addressed in the literature. Parker and Heywood (2000) showed that learners rarely think about floating and sinking in terms of forces. In a later study involving primary teachers and secondary trainee teachers, Heywood and Parker (2001) showed that

- by providing tactile experiences of forces acting on floating objects (the upthrust from the water, the weight force down) and the opportunity to explicitly identify the forces and the direction in which they act
- by investigating what happens when weight is kept constant while size varies
- and through encouragement of personal reflection on their learning,

teachers could not only identify the balancing of forces involved in floating and sinking, but could also extend the idea of balanced and imbalanced forces to a range of other situations. These features are, of course, classical conceptual change strategies. Our own research (Tytler and Peterson 2005) has shown that children improve markedly in their ability to investigate the flight of parachutes and whirlybirds (see the case study ‘Children engaged in air activities’ on p. 109) when they are able to conceptualise the weight force and upthrust from the air as separate and capable of independent manipulation. Hart (2002), using a variety of examples, shows the importance of clarifying with students the meaning they attach to the ideas surrounding force.

What are the factors that make such activities productive for young learners? Hadzigeorgiou (2002) argues that with young children it is more important to build experiential foundations than to explicitly teach concepts, and that these foundations include attitudes such as curiosity and experience in working in situations that provide a rich environment for exploration and feedback. Hadzigeorgiou worked with preschool children aged four and a half to six years on a challenge activity that involved them constructing as tall a tower as they could on a sloping surface using cans of varying diameter and weight. He
was able to show that children whose teacher provided a structured experience (clarifying questions, asking for predictions, pointing out significant results and providing further challenges) learnt much more successfully than those who were given the task without further support. Clearly, the teacher’s role in providing such scaffolding is critical. The study found that these young children could gain an understanding of what affected the stability of such structures without recourse to advanced ideas such as centre of gravity.

Vosniadou and Ioannides (2001) investigated the nature of a learning environment that successfully challenged Year 5 children’s intuitive ideas about force and resulted in improved learning. They characterised this as consisting of:

- taking into consideration and making explicit students’ prior knowledge
- the use of measurements (as with Activity 3.2; see p. 102), representations (such as force arrows) and models
- creating cognitive conflict through challenge activities (for example, by showing that the force needed to move an object is less than its weight, leading to a discussion of friction)
- paying attention to the order in which concepts are introduced
- talking through language problems with the class (for example, what energy or force might mean to scientists that is different to everyday meanings).

Yuruk, Beeth and Andersen (2009) worked with a teacher on a secondary level force-and-motion unit emphasising engagement in metaconceptual processes – that is, helping students become aware of their understandings and the way these are changing, monitoring their learning processes, and evaluating competing conceptions for their ability to explain real phenomena. The approach involved instructional activities such as poster drawing, group debate, journal writing and class and group discussion. They found that the class developed a higher level of conceptual understanding than a matched class taught using traditional instruction. At the primary level, Carruthers and de Berg (2010) worked with Year 6 students on a small-group inquiry and argumentation magnetic force sequence (e.g., Zembal-Saul 2009). They found that students spontaneously developed push–pull notions of force and were capable of working with rudimentary elements of argumentation (making claims supported by evidence). An understanding of forces interacting in pairs, however, was more difficult to achieve, in that students tended to think of magnets causing forces on nails but not vice versa.

Technology challenges involving the investigation of structures, or machines, offer a rich context in which to explore force ideas. Bennett (2009) investigated the use of practical activities with construction kits, involving geared machines. He concluded that students did not readily transfer their knowledge of gears to new design situations, and that simply giving children a kit with a set of instructions was not likely to encourage learning. The teacher’s intervention in guiding activity was crucial in focusing attention and developing thinking. The team developed a four-level approach to intervention:

1. What appears to be the problem? Can you explain it to me?
2. How have you tried to solve the problem?
3. Have you thought of …? (providing strong direction)
4. Here, let me show you.
Such an approach could be used for any design or investigation activity. It provides a natural way to assess students’ learning through determining the level of support a group needs to successfully solve a task.

Literacy and learning about force
Recent research has emphasised that learning involves developing an increasing capability to participate in the discursive practices (ways of talking and of doing things) of a subject area. In this view, science is acknowledged as a mixture of languages involving representations in a variety of modes, including such things as diagrams, text-based explanations and reports, tables and graphs, two- or three-dimensional models and even gestures (Lemke 2004). Tytler, Peterson and Prain (2006) explore the use of multiple representations in developing explanations of evaporation (see Chapter 9). Hubber, Tytler and Haslam (2010) explore the teaching and learning of force from a representational perspective. Russell and McGuigan (2001) argue that learning involves being increasingly able to use different representations to explain ideas, and their work provides further exploration of some of the ideas about force discussed above. In a study of teachers working with this principle, they showed that effective learning about gravity occurred as students were challenged to represent their explanations in different ways (force and other diagrams, written and verbal explanations, models) and think about how these differed from their own ideas. This approach is sometimes referred to as representational redescription.

The national curriculum project Primary Connections (Australian Academy of Science 2005) links science with literacy learning. As part of this focus, the units explore how science can be used to support students’ general literacy skills, but also articulates the particular literacies associated with science. In a stage 1 unit, Push-Pull, students are asked to generate labelled diagrams identifying motion, and pushes and pulls, and also descriptive observations of movement they had investigated. If we were to think about developing with students a vocabulary of force and motion, then that vocabulary in the wider sense must encompass not only words, but conventions to do with arrows and labels, time-lapse drawings, charts and graphs, and possibly even gestures. Thus, a discussion of the features of scientific representations is an important part of teaching and learning. Hubber, Tytler and Haslam (2010) argue for a representation-focused pedagogy that comprises the structuring of challenges involving the generation, negotiation and evaluation of representations. Understanding, from this perspective, involves the capacity to coordinate multiple representations and to appreciate that each brings a specific aspect of a phenomenon into focus. They showed that the challenge for teachers with this approach was, firstly, managing discussion of a variety of student inputs, and secondly, adopting the perspective that there are many ways in which science ideas can be represented, and not a single, given, ‘correct’ way, as is often assumed in texts.

Primary Connections has two more units dealing with force and motion besides ‘Push–Pull’. These are ‘On the Move’ and the stage 2 unit ‘Smooth Moves’, which introduces gravity and arrow representations of force.
Activity 3.4 Representing force and motion

- Revisit the representations of force and motion you generated in Activity 3.1 (see p. 100). Were the representations of you and your group similar? Could these be used to generate some useful conventions for representing force and motion?
- Discuss, in your group, your views about what is happening in each of the skateboard scenarios from Adams, Doig and Rosier’s (1991) paper. In coming to an agreement, note the different representations you draw upon to convince your colleagues, perhaps including verbal descriptions, diagrams with arrows or other devices, gestures or models.
- Discuss whether there is a particular set of representations you feel should be taught for this topic, and whether variation in students’ representations should be negotiated when teaching force and motion.
- Discuss how the idea of representational redescription fits with Vosniadou and Ioannides’ (2001) principles, and what implications there might be for your own planning.

CHAPTER 3 Movement and force

Learning about air and flight

Flight, which relates directly to movement and force, is a rich area for science investigation in the primary school. Often, however, units on flight focus on the technology of such things as kite or paper plane construction, rather than on the science underlying flight.

The science of flight involves consideration of the forces due to air: air resistance, the uplift of air on wings or the buoyancy of air in balloons. Thus, a discussion of air should precede any discussion of a flight sequence, particularly for younger children, who may not have a clear conception of the existence or properties of air (see Chapter 8).

Where does air exist? Children can be readily taught to say ‘air is everywhere’, but when asked if air is in a closed jar or cupboard, inside a room, under a table or in an open box, their responses can be surprising. Young children tend to associate air with wind, which is perceptible. If you wave a piece of paper in front of a child’s face and ask what is happening, the explanation comes in two quite distinct forms: one from children who think that air is created by the moving paper and one from those who think it is present but simply caused to move by the paper.

Some activities to establish the presence of air and the idea that air takes up space that you might like to discuss are as follows:
- Children attempt to collect air in plastic bags from various places, including cupboards, to explore their ideas.
- A tissue is squashed into an empty glass which is then upturned and plunged under water. Will the tissue be soaked?
CASE STUDIES
Children engaged in air activities

What follows is a series of flight activities and children’s responses to them that illustrate ideas about the forces involved in flight. The transcripts have been taken from a longitudinal study (Tytler and Peterson 2005) that follow a number of children over their primary school years to gain insights into their developing understandings. Some of the transcripts will show the responses of the same children interviewed some years apart to illustrate the nature of this development.

Paper drop
This is a predict–observe–explain (POE) sequence focusing on air resistance and flight. Try it yourself. In each case you should predict what will happen before trying it. The results will be unexpected.

In pairs, drop:
- two sheets of A4 paper, one held horizontally and one vertically
- an uncrumpled sheet of A4 paper and a crumpled sheet of A4 paper
- an A4 sheet of paper and an A4-size book
- an A4 sheet resting on top of an A4-sized book.

In the paper drop activity, most students will arrive at a conclusion that the air resists the A4 paper but that dropping it when held vertically minimises the surface that is pushing through the air and hence it will drop quickly (at least initially, until it skews off course). Younger students will often say the crumpled paper drops more quickly than the A4 sheet because it is heavier. Density, or compactness, is often confused with weight, so this is a good opportunity to have that discussion. The book falls more quickly because it has greater weight to overcome the action of air on its surface.

The real surprise and challenge offered by this activity is the fact that the paper, in the final drop, falls along with the book. The reason is that the book is pushing the air that would be resisting the paper on its own. The paper is not needing to force through air and effectively falls as it would in a vacuum. This may remind you of the experiment conducted by Neil Armstrong on the moon. He dropped a hammer and a feather to find that, in the absence of an atmosphere, they fall at identical rates – as argued by Galileo. Some people argue that the paper is in the book’s slipstream, which is, in fact, the same explanation. Some argue that air comes around the back of the book because of turbulence and holds the paper on. This is substantially incorrect, although there is turbulence and there is some complicated science associated with turbulence.

One five-year-old child explained this counterintuitive result very quickly and convincingly by pointing out that the paper acted just like another page in the book, and so would be expected to fall with it.

There is a lot of fun to be had with this activity by dropping the book and paper from different heights or varying the position and extent of overlap of the paper.

Parachute
The following flight activities, featuring parachutes and whirlybirds, are common as part of primary school science sequences. These activities were constructed in the longitudinal study as explorations of the effect of canopy size and weight in the case of the parachute, and wing size and weight for the whirlybirds. These activities work well as probes for eliciting children’s ideas and also as investigations that help establish ideas of variable control. The transcripts are taken from parts of interview sequences with the same children over their first four years of school and are reported in Tytler and Peterson (2005).

In grade prep (kindergarten year), Anna experimented with parachutes and described how they worked in terms of uplift from the parachute and linked to the idea of hot air:

Interviewer: How did the parachute make it a better landing?
Anna: Because it was lighter … because it’s got a gas inside it because it’s like a hot balloon and it’s a bit fatter.

Eighteen months later in Year 1, children were shown four parachutes, two with large and two with small plastic bags as canopies; each had either a small or a large plastic model of a parachutist in it. Children were challenged to separate out the effect of canopy size and weight. It is a common finding with children’s conceptions that, within
the change, there are ideas they keep returning to. Anna’s idea of parachutes making people lighter seems to persist. Anna seems to regard the model and canopy as one object, differing in weight. Thus, when challenged to explore the effect of canopy size, she compares two with the same size canopy:

Anna: This one will fall a bit faster than this one.
Interviewer: Why is that? They’ve got the same size canopy.
Anna: No, but this one is a bit lighter than this one – this one has nothing inside it and this one does.

Whirlybird

Whirlybirds, or spinners, are intriguing flight devices that can be manipulated to vary in the way they spin and drop. The instructions are set out in Figure 3.2.

Whirlybirds provide the opportunity for the development of students’ knowledge of investigations: hypothesising, fair testing, measuring, recording and reporting. Timing the fall is difficult; comparing different designs two at a time is probably the most productive thing to do if you don’t have access to a stopwatch and a balcony from which to drop them. To keep track of what is happening, children should modify one aspect at a time and, preferably, retain each modified design.

Children were shown six paper whirlybirds that spin as they fall. There were three pairs of whirlybirds, each with different wingspans – short, medium and long; one of each pair had a paperclip attached. Students were asked to work out which whirlybird fell the slowest. They were challenged to give their reasoning and, where appropriate, to provide evidence to support their assertions. Children performed this task at the end of grade prep and again at the end of Year 2.

This activity is a variable control activity, but there were interesting instances of a range of approaches.

Karen, Year 2

In grade prep, Karen, without really considering the science, had organised a play-off between pairs of whirlybirds, with winners playing winners to find the slowest. In Year 2, when she is posed the task, she immediately drops one whirlybird and starts entering a number in a table on a sheet of paper. This confuses the interviewer until he realises she is counting under her breath to measure the time of fall:

Interviewer: How did you know what to write in it?
Karen: Medium with clip ... small with clip ... 10 seconds ...

By this time Karen is unstoppable. She had launched straight into a planned method for measuring and recording. She proceeds to fill in the table showing times for each whirlybird, identified appropriately by wing length and clip/no clip before reviewing results:

Karen: So probably the one without clip takes the longest to go down. And the small one doesn’t with the clip. It takes the ... smallest to go down and it, um, it wasn’t ... (?) The big one with clip took 10 seconds and so the big ones are probably first, and the mediums could be, like, second, but the ones with the clips ... and so it’s like ... ’cause, like, the ones without folded up are better than the ones with the clips ’cause the clip’s heavier and it pulls them down.

Karen’s investigation does not conform to the interviewer’s expectation of a variable control.
Assessing children’s learning

One of the major implications of constructivist or sociocultural views of learning is that children’s understandings need to be continually monitored as part of the ongoing discourse of the class. If the conceptual conversation is to be rich, the teacher should be encouraging all children to participate in the generation and evaluation of ideas. Particularly from a representation-focused pedagogical perspective, these ideas can be diverse. A child can best be supported to embrace experiment, but it is nevertheless very effective in identifying what is happening. However, she finds it hard to construct a clear test to demonstrate the effect of the wings.

**Calum, Year 2**

When Calum was in grade prep he had not come up with a clear view of why whirlybirds fly, mentioning neither weight nor air. His exploration was therefore unfocused. In Year 2, however:

- **Interviewer**: What do you think causes that spin?
- **Calum**: Probably … the paperclip to pull it down and, um, because of the air pushing up … instead of them going up it would have to push, the air would have to push it away so it goes round.

**Interviewer**: What I'd like you to do is to do an experiment with this just to find out which one actually drops slowest to the ground and why that one is slowest.

- **Calum**: Probably it’s because the paperclip pulls it down. And you can see the one without the paperclip … spinning …

In the intervening year, the class had been exposed to whirlybird and paper plane flight as classroom activities, but it is not clear how much explicit teaching about the science occurred and the outcome was clearly different for the different children.

**The science of whirlybirds**

The spinning effect is due to the action of air on the wings as it rushes past the dropping whirlybird. You can check this by holding the whirlybird and pushing up on one wing with your finger. The body moves back as the wing is forced up. Pushing up on the other wing has the opposite effect. You can see that the net result is a spinning set of forces. Flipping the wings causes them to spin in the opposite direction.

The longer the wings, the slower the drop because of the uplift on the greater wing area. The more paperclips, the faster the drop and spin because of the greater weight.

**Activity 3.5 Strategies for teaching about flight**

Try the above flight activities and discuss with colleagues how best to set up the investigation to explore the science ideas and present findings.

- Construct some annotated force diagrams to clarify the factors that influence the flight of the paper, the parachute and the whirlybirds.
- In the paper featuring these transcripts, we argued that children’s ability to conduct investigations was dependent on their understanding of what they were exploring. Consider the three transcripts and discuss what evidence exists for this.
- How would you approach this exploration and the presentation of data to help children understand these flight phenomena?
richer and more flexible understandings if their current beliefs and understandings are known. A discussion of the purposes and forms of assessment can be found in Chapter 1 (see the section 'Assessment for student learning' on p. 35). Formative assessment is used to shape and plan the teaching program and support children’s learning. It is important that a teacher takes children’s ideas seriously and encourages and supports them to monitor their own understandings. Summative assessment involving judgements about children’s understanding at the end of a teaching and learning sequence has more to do with credentialling than supporting learning. Nevertheless, being clear about what learning is intended and having a view about the different levels of understanding that can be held by children are powerful aids to planning and responding. The way assessment can be embedded in unit planning is further discussed in the section 'Learning about simple machines' later in this chapter (see p. 120).

Levels of understanding of movement and force
Ultimately, at the end of a classroom sequence on movement and force, we should be attempting to arrive at some overview of the level of each child’s understandings. If a sequence has a coherent, conceptual agenda, it is not adequate to simply add marks given on many different items. We need a clear assessment framework.

An assessment rubric for movement and force
One of the methods primary teachers have used to help plan and assess children’s understandings is the use of assessment rubrics. These are descriptors of different levels of, for instance, understanding of movement and force, cast quite broadly so they can be used across activities and probes. What follows is a possible example based on the research into alternative conceptions described above.

- **Level 1** – Can describe simple situations involving movement and force using appropriate terminology, such as ‘push’, ‘pull’ and ‘speeding up’. Can make sensible observations of a variety of movements using appropriate, simple language.
- **Level 2** – Can make observations about movement and force situations and generate interpretations based on patterns, such as ‘heavy things need more force to move’ or ‘whirlybirds with longer wings fall slower’. Uses the language of push and pull, but may harbour varied notions of forces residing in moving objects and has confused ideas about gravity and friction.
- **Level 3** – Can describe a variety of motions in detailed terms and can attempt reasonable explanations of different motions using representations of the actions of single forces of different types (gravity, friction, forces due to air, pushes and pulls). Has a basic understanding of gravity and upthrust. May still harbour a variety of alternative conceptions.
- **Level 4** – Can describe more complex motions in specific terms, such as ‘vibrating’ or ‘orbiting’. Can coordinate representations of combinations of forces to explain an object’s motion in situations where they may oppose or where an object is balancing under the action of different forces. Can attempt interpretations of complex motions (such as whirlybird flight) in terms of detailed consideration of different forces.
Assessing children’s approach to exploration

This chapter has argued that children learn best if their ideas are challenged and supported using investigative activities in which they test ideas against evidence. We have argued that the ability to approach, design and carry through investigations is dependent on children’s level of knowledge. Thus, we need to develop ways of assessing investigations as well as understandings. In analysing children’s performance on a range of tasks, such as the whirlybird or parachute tasks or open explorations of animal behaviour, we developed descriptions of different levels at which children approached exploration. These levels are shown, with examples, in Table 3.1. They represent qualitatively different ways of reasoning about ideas using evidence. We believe they represent a mixture of children’s level of curiosity, their intuition and their understanding of the way ideas are used in science. For example, science explanations are a specific genre of reasoning with language that needs to be modelled for young children. For further discussion of the importance of understanding how ideas and evidence are related in science, of argumentation, and particularly the importance of understandings of the NOS, refer to Chapter 1.

In Table 3.1, illustrations of the whirlybird exploration are given, together with examples of the types of conceptual understanding that tend to be associated with each level.

Reasoning in science, which is closely related to children’s coordination of ideas and evidence in Table 3.1, is often also related to the idea of ‘argumentation’, where students are encouraged to make judgements about claims (ideas) based on evidence, and engage with
competing claims and evidence. Simon, Erduran and Osborne (2006) have worked with
teachers to develop a model for introducing argumentation activities into science classrooms,
aimed at modelling the way in which knowledge is supported with evidence in science. The
UK work on argumentation has produced the curriculum materials *Ideas, Evidence and
Argument in Science Education* (IDEAS), which are being widely used. These involve activities
that challenge students and encourage them to hypothesise and resolve claims and
counterclaims on the basis of evidence. Argumentation is also discussed in Chapter 1 (see
under ‘Main components of constructivist models and schemata’ on p. 24).

**TABLE 3.1 Children’s approach to exploration: a reasoning rubric**

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>WHIRLYBIRD EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Ad hoc exploration</td>
<td>No systematic observations or comparisons are made nor use of a guiding explanatory purpose given. Exploration at this level is restricted to low-level interpretation that lies close to what is observed. Children explore one whirlybird or parachute at a time without explicitly comparing characteristics. They do not explicitly seek patterns, but focus on the flight of individual whirlybirds.</td>
</tr>
<tr>
<td>2 Inference searching</td>
<td>The inference could be about patterns in what is observed or about explanatory ideas. Children explore on a try-it-and-see basis without a noticeable sequence, but leading to some hypotheses or inferences. They notice things, comment and infer underlying patterns or causes. Exploration at this level is data-led, but with some conceptual interpretation. Children compare pairs of whirlybirds based on some factor of interest and without a plan based on an idea. They may be able to interpret the outcomes in terms of whether long or short wings fall faster or, if asked, even provide some explanation.</td>
</tr>
<tr>
<td>3 Hypothesis checking</td>
<td>The hypothesis could be about relations between variables or about theoretical ideas. Children carry out focused observations or interventions that involve trying out an idea or following up a prediction with some conceptual basis. Explorations have a recognisable hypothesis driving them. Explorations at this level is theory-led, but does not necessarily separate variables. Children take the lead in developing a strategy to check ideas (for example, longer wings slow down the whirlybird) about what affects whirlybird flight. Generally, at this level they are working on an explanatory hypothesis, such as that long wings catch the air more.</td>
</tr>
<tr>
<td>4 Hypothesis exploring</td>
<td>Strategic search for evidence to refine or distinguish between hypotheses or rule out other possibilities. Setting up checks of ideas generated and dealing explicitly with the possibility of confounding variables or other limitations on experimental design. Explorations at this level acknowledges the interdependence of data and theory. For the whirlybird flight, children spontaneously try out competing ideas; for example, by altering conditions in an ordered way, controlling for variables of weight and wingspan, and exploring the interaction between stability and weight and wingspan. The ideas and explanations at this level are often complex and speculative.</td>
</tr>
</tbody>
</table>
Planning for conceptual development with the 5E instructional model

In technological applications, forces are utilised and manipulated in a variety of ways to perform useful functions. The next two sections of this chapter will model how the 5E scheme can be used flexibly to plan coherent learning sequences on the manipulation of forces using simple machines. This section describes how the 5E framework discussed in Chapter 1 (see the section ‘Constructivist teaching models or schemata’ on p. 22) has been applied by teachers and curriculum writers in lesson and unit planning. Then, the principles of simple machines are explored in three contrasting lesson sequences planned according to the 5E framework.

As discussed in Chapter 1, the 5E scheme is gaining currency as a framework for thinking about effective teaching and learning. The model has so far had applications in program development in schools (for example, for lesson and unit planning), commercial curriculum resources (for example, Primary Connections) and policy development (for example, a modified version of the 5E scheme, the ‘e5’, is central to a school improvement model initiated by the Victorian Department of Education and Early Childhood Development). Bybee and his colleagues developed the 5E instructional model in 1989, influenced by historical instructional models - for example, John Dewey emphasised the importance of experience and reflection, and a commitment to supporting deeper learning through inquiry, and Johann Friedrich Herbart emphasised that effective pedagogy allows students to discover the relationship among experiences - and the contemporary three-phase learning cycle of Atkin and Karplus (1962) that promoted guided discovery (see Bybee et al. 2006).

To recap, the 5E instructional model consists of five phases: engagement, exploration, explanation, elaboration and evaluation. Each phase has a specific function and contributes to coherent instruction by the teacher and the formulation of better scientific and technological knowledge, attitudes and skills in the learner. The scheme is based on the premise that students learn best when allowed to work out explanations for themselves over time through a variety of learning experiences structured by the teacher (Hackling 2006). Social construction of meaning is promoted through collaborative work and the joint construction of explanations based on common experiences – social constructivism is discussed further in
Chapter 1; see the section ‘Social constructivism’ on p. 13. The focus on experience to build conceptual understanding means that the 5E framework supports an inquiry approach to science teaching.

The Primary Connections (AAS 2005) resource is an example of how the 5E scheme can act as the framework for planning inquiry-based primary science units. As described in Chapter 1, the resource integrates science and literacy. Table 3.2 describes the purpose of each phase based on Bybee et al.’s (2006) original model, and outlines how the framework as applied in Primary Connections incorporates an emphasis on multiple representations to develop the literacies of science. Each phase advocates particular science literacy strategies that allow students to engage with different textual forms and represent data and ideas in multiple ways.

| TABLE 3.2 The 5E model with a science literacy focus and assessment framework |
|---|---|---|
| PHASE | PURPOSE | ROLE OF TEACHING AND LEARNING ACTIVITY, EMPHASISING LITERACY PROCESS AND PRODUCT | ASSESSMENT FRAMEWORK |
| Engage | • An object, event, problem or question is used to engage students with the topic and to elicit students’ current knowledge and experiences.  
• Activities make connections between past and present learning experiences, expose prior conceptions, and point student thinking towards the learning outcomes of current activities. | • Activity or multimodal text set context and establish topicality and relevance.  
• Motivating/discrepant experience creates interest and raises questions.  
• Open questions, individual student writing, drawing, acting out understanding, and discussion to reveal students’ existing ideas and beliefs so that teachers are aware of current conceptions and can plan to extend and challenge as appropriate. | Diagnostic |
| Explore | • Objects and phenomena are explored through teacher-guided hands-on activities.  
• Current conceptions, processes and skills are identified and conceptual change is facilitated.  
• Activities help learners use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct preliminary investigations. | • Investigations to experience the phenomenon, collect evidence through observation and measurement, test ideas and try to answer questions.  
• Investigation of text-based materials (for example, newspaper articles, Web-based articles) with consideration given to aspects of critical literacy, including making judgements about the reliability of the sources or the scientific claims made in the texts. | Formative |
| Explain | • Students’ attention is focused on particular aspects of the prior learning experiences.  
• Students explain their understanding of concepts and processes by drawing on their experiences from the engagement and exploration phases.  
• Conceptual clarity and cohesion are sought as the teacher introduces new concepts and skills. | • Student reading or teacher explanation to access concepts and terms that will be useful in interpreting evidence and explaining the phenomenon.  
• Small-group discussion to generate explanations, compare ideas and relate evidence to explanations.  
• Individual writing, drawing and mapping to clarify ideas and explanations. | Formative (sometimes Summative) |
The Primary Connections units provide a model for how a holistic approach to assessment can be promoted in 5E lesson sequences using the diagnostic, formative and summative assessment framework (see Table 3.2). (Chapter 1 has more detail on assessment in the context of discussions about externalising and modifying students’ ideas, metacognition and formative assessment; see the section ‘Assessment for student learning’ on p. 35.) Diagnostic assessment typically occurs during the ‘engage’ phase, and formative assessment during the ‘explore’, ‘explain’ and ‘elaborate’ phases, while summative assessment commonly occurs in the ‘elaborate’ and ‘evaluate’ phases. Appendix 3.1 (see p. 140) gives examples of assessment strategies that teachers can use within this assessment framework.
Activity 3.8 Classifying assessment activities

The three forms of assessment used by Primary Connections are diagnostic, formative and summative assessment. A holistic assessment framework should incorporate each of these forms, recognising that each form is based on assumptions about what and how learning can be achieved, and the role of the teacher and learner in the learning process.

The assumption behind diagnostic assessment is that students come to the classroom with understandings about the world and experiences that may be useful to the science topic. Diagnostic assessment strategies include gathering information about what students already know and are able to do, allowing for identification of gaps or alternative conceptions in prior learning, eliciting students’ questions or wondering about a phenomenon or topic, and using students’ prior knowledge and experiences to inform the teaching and learning process.

The assumption behind formative assessment is that there is a gap between the current level of knowledge and what the learner can potentially do. Formative assessment strategies include focusing on the student during the learning process, guiding and informing the teacher so that the next steps for the students’ learning can be planned, monitoring whether students’ questions are being responded to, and helping the students to learn and have positive learning outcomes.

The assumption behind summative assessment is that students’ learning can be measured against learning outcomes or standards. Summative assessment tasks include evaluating the achievement of learning outcomes, providing a judgement of what has been learnt and what change has occurred in the students’ understanding or performance, generating grades for assessment, and providing comparative information about what has been learned.

- Look at one of the Primary Connections units that deal with force and motion: ‘On the Move’, ‘Push–Pull’ (both level 1) or ‘Smooth Moves’ (level 2). Describe the assessment framework used in the unit by identifying and classifying assessment activities as diagnostic, formative or summative. For each activity, describe what a teacher can learn about the student and their progress.

- When planning a learning sequence on the action of forces, the teacher ensures there are opportunities for students to display their understandings at many points during the sequence. Classify each of the following activities as non-assessment, diagnostic, formative or summative activities – you do not know the context in which these activities are being used; that is, when the activities will occur and the teacher’s purpose. Also discuss the role that context plays in determining the purpose of an assessment activity. The activities are as follows:
  - Individual and class discussion takes place about students’ responses to a circus of activities designed to challenge preconceptions.
  - Once a week, the teacher asks students to complete a journal that answers teacher-specified questions aimed at student reflection on concepts, concerns, feelings and responses to activities. This is collected and the teacher responds to each reflection in an affirmational (positive) way.
  - The teacher circulates as the groups brainstorm ideas.
  - Students develop a PowerPoint presentation of a machine they have designed.
  - Students complete a sequence of questions from a textbook.
  - A 10-question quiz is conducted at the beginning of every second lesson that relates to previous lessons and introduces the concepts of the next two lessons.
  - The teacher uses targeted questioning as they enact a role-play of gears.
The *Primary Connections* units include lesson plans for each 5E phase, an approach that teachers can use in their own lesson planning. Other resources advocate the use of the entire 5E framework within each lesson. For example, Moyer, Hackett and Everett (2007) develop what they call Learning Cycle Lesson Plans based on inquiry principles. According to this interpretation, a lesson should be focused on ‘explorable questions’, which are questions that a learner can answer through firsthand experiences with the materials. Such questions are called ‘investigable’ questions in Chapter 10, and ‘productive’ questions elsewhere in this book. In these lessons, activities are used to generate and provide context for these questions, which are then explored. Explanations are then constructed by the students and the teacher, which are then applied to new contexts. The learning is then evaluated.

As demonstrated above, the 5E model has a wide range of applications. As with any schema, there are benefits and issues associated with adopting the 5E model for planning instruction. A critique of the 5E model can be found in the online Appendix 3.2.

**Learning about simple machines**

In this section, we will explore different types of simple machines and how they work to modify force and motion. Following that, we will use the 5E model to plan learning sequences for simple machines.

**The science of simple machines**

Forces have the capacity to affect the motion or change the shape of objects. The history of the invention of technologies designed to move or modify objects (such as piles of dirt, doors or bicycles, or even ourselves) is the history of how we have learnt to modify the action of forces to our advantage. We are talking here of the principles of simple machines, which can:

- magnify a force applied
- reduce a force opposing motion
- change the direction of a force
- speed things up or slow things down.

The compelling aspect of simple machines that makes them a worthwhile topic in primary schools is the familiarity children will have with examples of such machines in their lives: in the kitchen, children use scissors, can-openers and egg-beaters; in the shed, they see wheelbarrows, shovels, screwdrivers and pliers; and for leisure activities, they use bicycles, scooters and mechanical toys. Once learnt, the principles of simple machines offer a new way of looking at how these everyday devices work. Students may be prompted to use the term ‘mechanical advantage’ to describe how the simple machine makes life easier – mechanical advantage refers to the fact that you can use a machine to produce a large load force (e.g., to lift a large weight) using a small effort force.

Figure 3.3 shows an interpretation of the simple machines embedded in a can opener. The relative size of the load force (from the blades onto the can) and the effort force are in inverse ratio to the distance of each from the fulcrum. Similarly, the length of the turning handle gives a mechanical advantage in proportion to this length compared to the radius of the blades that do the cutting. The gears are of equal size and rotate in opposite directions at the same rate. The blade is also a machine, acting as an inclined plane magnifying the sideways tearing force on the can that is larger than the pressure applied by the point of the blade.
Everyday examples of simple machines can be examined to show the different ways in which they manipulate force. The principles of a short list of simple machines and the mechanical advantages that they provide are briefly described below.

**Levers**
Using a lever involves rotating a lever arm around a pivot (also called a fulcrum) to create a ‘load’ force. If the distance from the fulcrum to where the effort force is applied is further than that from the fulcrum to the load force, then the load force is larger than that applied; the force is magnified. An example would be using a screwdriver to open the lid of a paint tin, where a small force applied at the screwdriver handle creates a large force at the screwdriver tip to prise open the lid. You can find details of simple machine principles on many websites, such as that of the Commonwealth Scientific and Industrial Research Organisation (CSIRO; see, for example, www.csiro.au/scope/episodes/e73.htm).

**FIGURE 3.3** The can-opener as a simple machine

![Can-opener diagram](image)
There are three types of levers:

- **1st-class levers** – the fulcrum is between the effort force and the load force (e.g., scissors, a crowbar)
- **2nd-class levers** – the load force is between the fulcrum and the effort force (e.g., a wheelbarrow, nutcracker)
- **3rd-class levers** – the effort force is between the fulcrum and the load force (e.g., a fishing rod).

The ratio of the load force to the effort is in inverse proportion to the distance of these from the fulcrum. Thus, for a pair of pliers, if the force applied by the hand is five times as far from the fulcrum as the point of grip of the pliers, then the load (grip) force which is applied to the object in the pliers will be five times the effort force from the hand. This represents a five-fold mechanical advantage. The way this works, including for the turning handle on a can-opener, is shown in Figure 3.3 (see p. 121).

**Gears**

Gears are used to transfer force from one gear to another. Gears can do three things:

1. speed things up
2. slow things down
3. change the direction of the force.

Lehrer and Schauble (1998, pp. 4–5) explain how gear trains (sequence of interlocking gears) work:

> Each tooth on the driving gear must push one tooth on the gear that it drives. The turning speeds of the two gears must depend on the number of pushing teeth and the number of teeth that get pushed. Pairs of meshed gears must turn in opposite directions, or that small gears turn faster than large ones. Every other gear in a train of meshed gears will move in the same direction.

**Pulleys**

A pulley changes the direction of the force or effort. A pulley with one wheel does not reduce the force required to lift the load; however, it is easier to pull down than it is to pull up. A pulley with two wheels makes it easier to lift a load by halving the effort required (Oxlade and Hawken 1998).

**Inclined planes, screws and wedges**

Inclined planes increase the distance covered (e.g., in pushing a wheelbarrow up a ramp rather than lifting it) but decrease the effort needed to move that distance. This principle also applies to screws, which are essentially inclined planes threaded around a central shaft, and to wedges and blades, which are like portable compound inclined planes. In each case, a small force translates into a large load force at right angles to the effort, but over a smaller distance.

**Wheels and axles**

Wheels reduce the friction that opposes motion. This happens because for a wheel, the point of contact with the ground does not scrape along the ground. The key idea with the wheel is the relationship of the axle and vehicle to the wheel.
As an example of the way in which simple machines have transformed our lives, let's consider the role of wheels in humankind's attempt to manipulate and improve its surroundings. Wheels are often described as humanity's greatest invention. So much of human social history has to do with transport, with getting things from one place to another with a minimum of fuss and energy expenditure. Some of the great mysteries of ancient civilisations involve questions of transport. For example, how did the Egyptians get the stones in place on the pyramids? How were the Easter Island statues transported to their sites and erected?

The most plausible theories concerning the pyramids involve the use of rollers. The roller, in fact, is the forerunner to the wheel. The disadvantage of rollers is that they are not attached to a carriage. They have to be repeatedly taken from the back of whatever is being transported and brought to the front again. Having an axle solves that problem, though attaching the axle and arranging for the wheel to be able to turn freely is a problem in itself. Some axles are fixed, with the spinning of the wheel made relatively frictionless by using ball bearings or lots of grease. Other axles spin, such as the driving axle on a car that causes the wheel to turn. If you look carefully at a bicycle wheel, you will see that the axle is fixed and the wheel spins around using a sleeve arrangement. When they make model carts in a classroom, children can have a lot of difficulty in solving this wheel–axle problem.

Because of the need for strength to carry loads over rough terrain, early wheels were solid and bulky items. Once road-building technology improved, it was possible to use a lighter design of wheel, which made carts easier to pull. Early spoked wheels were constructed from wood, but once metal technology developed, the use of taut wire on bicycle wheels and metal spokes on trains and buggies became possible. Early coach wheels used metal bands that were heated and placed on the wooden rims, then hosed down with cold water. The resulting contraction caused the band to grip tightly on the rim. The metal gave protection against the wear and tear caused by constant contact with the road surface. Rubber technology allowed for a lighter tyre that improved grip on the road and gave a gentler ride because of the natural stretch of the material. Inflatable tyres are lighter again and make use of the compressibility of air to give a natural springiness. The history of transport is thus a good vehicle for a discussion of materials and technology.

**Children’s ideas about simple machines**

In the research on simple machines, interest has focused on the extent to which children can develop generalised understandings of machine principles through direct observation and exploration, and at what point they need guidance in developing these understandings.

In researching children exploring rollers and ramps, Liu (2000) found that physical actions and reasoning/conceptual understandings developed together, as students were able to conceive various relations between characteristics such as slope and speed of rolling, and elaborations on the different characteristics of rollers, as they experimented.

Lehrer and Schauble (1998) found that primary school children perceive gear trains in a variety of ways, focusing on different aspects such as direction, plane of turning, and motion. But while children can develop superficial understandings quite readily through direct observation, deep understanding does not readily emerge without considerable reflection.
Children’s reasoning became more general, formal and mathematical as problem complexity increased, and Lehrer and Schauble argue that formal mathematical reasoning about gears may develop when this provides a clear advantage over simple causal generalisations, such as ‘If I turn a gear this way, the adjoining gear always turns the other way’. Lehrer and Schauble recommended the use of context-based technology and design problems to focus children’s attention on developing and revising hypotheses to develop explanations that would account for observed regularities.

When examining gears and mechanical advantage in the context of Lego robotic design, the understandings of nine- to 10-year-old children of direction of turning, relative speed and number of revolutions were enhanced, but they had difficulty providing the rationale for choosing gear arrangements that made the robot faster or slower (Chambers, Carbonaro and Murray 2008). Because research has shown that it is difficult for students to understand mechanical advantage through direct observation of gear functioning (Chambers, Carbonaro and Murray 2008; Lehrer and Schauble 1998), guided-inquiry instructional approaches are advocated to support conceptual development during construction design activities.

There is increasing interest in embodied cognition as the idea that we understand the world through bodily relations; for example, in perceptions of touch or spatial relations (as in mental imagery and spatial metaphors). We can see how this may be a critical factor in children’s understanding of forces, and how machines work. We can perceive, for instance, the effect of a lever by imagining ourselves pushing. Thus, an advocated strategy is to have children work with large-scale levers or pulleys or inclined planes to provide sensory experiences around which perceptually based understandings can develop. Having children explore simple seesaws, for instance, can provide powerful insights into how balance is affected by the relationship between distance from the fulcrum and relative weight. In an important sense, this notion of embodied cognition shifts the focus of attention away from ideas being situated purely in the mind, to a realisation that our understandings are distributed in our local environment (distributed cognition) as well as being highly perceptual in nature.

**Designing lesson sequences for simple machines using the 5E model**

In this section, we demonstrate how the 5E framework can be applied in different ways to the planning of units about simple machines for early and middle years students. Three units of six lessons each have been constructed to illustrate how activities can be used differently across a 5E sequence.

**Exemplar 5E lesson sequences**

Table 3.3 outlines three units focusing on simple machines. Units 1 and 2 include activities informed by preservice teachers planning for teaching years 3 and 4, and unit 3 is based on an early years sequence developed by practising teachers. Unit 1 explores levers, inclined planes, gears and pulleys in a variety of contexts, leading to an elaboration of simple machine principles through a design challenge. Unit 2 uses the context of the playground to explore levers and inclined planes, with elaboration where the students design playground or game equipment that incorporate levers and inclined planes. Unit 3 focuses solely on wheels, exploring the nature of wheels in detail. All
units culminate in a design challenge relevant to the contexts explored through the unit. The key activities in each lesson are listed; the numbered and italicised activities are described in more detail in the next section. Note that some activities are incorporated in more than one unit sequence to illustrate that there is more than one way to use activities within the 5E framework. Activities may be applied at different points in the unit and serve different purposes in the learning sequence.

Activities for use in the simple machine lesson sequences
The italicised activities numbered 1 to 13 in Table 3.3 are elaborated on in the following sections. These descriptions include different approaches to the activities, links to the 5E framework and assessment, and links to technology.

1 Mystery boxes
Children are asked to rotate around four tables, each with a mystery box, butcher’s paper and pens. Children take the items out of the box one by one, name them, and compare them to each other. On a piece of butcher’s paper, children write responses to questions such as: How

| TABLE 3.3 Simple machines units using the 5E instructional model |
|---|---|---|
| LESSON | UNIT 1 | UNIT 2 | UNIT 3 |
| 1 | **Engage**  
Challenge: How can I separate this piece of paper into two pieces with straight edges?  
*Mystery boxes* (1)  
KWL chart – complete K and W  
Discuss and add key words raised during the lesson to a word wall | **Engage**  
*Analysis of simple machines in pictures* of different playgrounds and Honda Accord commercial video (7)  
KWL chart – complete K and W | **Engage**  
Looking at wheels on tricycles and pushers (10) |
| 2 | **Explore**  
*Exploring levers* (2)  
*Exploring gears* (3)  
*Exploring pulley systems* (4)  
*Exploring inclined planes* (5) | **Explore**  
*Exploring levers* (2)  
*Exploring inclined planes* (5) | **Explore**  
Role-modelling wheels (11)  
Exploring the science of rolling down slopes: ramproll (12) |
| 3 | **Explain**  
*Representing force in simple machines* (6) | **Explain**  
*Classification and differentiation activities* (9) | **Explain**  
Excursion to a science resource centre, such as a museum (13) |
| 4 | **Elaborate**  
*Analysis of simple machines in video and pictures* (e.g., Rube Goldberg video) (7)  
*Design challenge*: design a Rube Goldberg machine (8) | **Elaborate**  
*Design challenge*: design and construct playground equipment or game equipment (8) | **Elaborate**  
*Design challenge*: cart construction (8) |
| 5 | **Evaluate**  
Complete design of machine in groups. Students present design and as a class decide how the group designs will be put together as one machine.  
KWL chart – complete L | **Evaluate**  
Students present their equipment and are peer-, teacher- and self-assessed  
KWL chart – complete L | **Evaluate**  
Hold a cart derby in the schoolgrounds  
Teachers and students evaluate their designs |
do you think the tool works? Draw it and label what you know. What is it used for? What would we do if it did not exist? What makes them all different?

Mystery boxes may contain objects or photos such as:

- gears of different sizes (e.g., can-opener, egg-beater)
- levers: first-class levers (e.g., seesaw, claw hammer, crowbar, scissors, pliers); second-class levers (e.g., wheelbarrow, paper cutter, door, nutcracker, garlic press, bellows, bottle opener); third-class levers (e.g., fishing rod, hammer, cricket bat, hockey stick, golf club, tennis racket, shovel, pitchfork, hoe, broom, tweezers, ice tongs, children’s arms and legs)
- pulleys: pulleys and weights, photos of pulleys for lifting objects (e.g., flag and flagpole, pulley clothesline, blocks and tackles, large cranes, chain hoists, hydraulic systems)
- inclined planes and ramps (e.g., screws, wedges, nails, toys that have ramps).

2 Exploring levers

For each of the following activities, children are asked to explore the materials and consider the problems posed. As they carry out the activity, children can discuss what will happen if the weight is changed, the fulcrum moved, or the load or effort increased. Children can log predictions prior to each change and record observations in a science journal. The language of fulcrum, effort, load and force can be introduced to students, and the teacher can model how to use this language when making predictions. Students may also be encouraged to identify some ‘explorable’ questions that arise out of the activities.

By exploration of the following, children should be able to:

- recognise and name the fulcrum, effort, load and force (output)
- name the three types of levers
- investigate changes that occur in force and load when a fulcrum is used.

_Lifting the load_

In this activity, children are asked to use a 30 cm rule as a first-class lever: tape a pencil as the fulcrum at the 5 cm mark and connect weights to one end of ruler as the load. Students should now find the easiest way to lift the load; that is, how to lift it using minimal effort. Begin by asking students how difficult/easy it will be for them to lift the weight, and why they think that? Is it possible to lift the load using another weight less than that of the load?

_Catapult_

Children are asked to use a 30 cm rule as a first-class lever: tape a pencil as the fulcrum at the 5 cm mark and place an eraser as the load at the short end. Students drop beanbags onto the longer end, trying to get the eraser to hit a piece of paper on the wall. Discuss with students what they think will happen when they drop the weight from a certain height, and why? Mark where the eraser hit on the paper and note in the journal the weight dropped (force) and the position of the pencil (fulcrum) in centimetres.

_Making a wheelbarrow_

In this activity, children are asked to use a 30 cm rule as a second-class lever: place a weight at 10 cm on the rule as the load, rest the long end on a table, and connect a force meter to the shorter end. Students measure how much force is required to lift the load when it is placed at different points along the rule. It is worthwhile discussing with students how the force meter acts like a spring balance that tells them the amount of force applied to the lever.
**Going fishing**

In this activity, children are asked to use a 30 cm rule as a third-class lever: tape string onto the 30 cm end of the rule and tie a magnet onto the end of the string, then hold onto the 0 cm end of the rule with one hand, attach a force meter at 15 cm, and place metal objects ("fish") of different weights on the table. Pull upwards on the force meter to pull up the fishing rod. Students are using the rule as a fishing rod and measuring the amount of upwards force required to ‘catch’ or lift fish of different weights. They can also explore the effect of placing the force meter (effort) at different points along the rule. Discuss with students what they think will happen to the amount of force required to lift a weight if it is placed closer to the supporting hand (fulcrum) and closer to the string (load), and when different fish (load) are caught.

**Extension**

Students can brainstorm, draw and build other examples of when they might use first-, second- and third-class levers.

**3 Exploring gears**

**Gear chains**

In this activity, children are asked to create different gear trains and record changes in the direction and speed of the gears. Try gear trains with different numbers of gears. Have students predict the direction of the last gear, or how many revolutions (turns) the different gears will do in relation to other gears. Students can document the number of revolutions against the number of teeth (e.g., gear 1 has 10 teeth and turns once when placed with a smaller gear with five teeth that turns twice).

Students should be able to:

- identify the driver, the follower and the teeth
- recognise that, within a gear train, the more teeth a gear has, the slower it will rotate
- recognise that gears in a gear train will alternate direction.

**Extension**

Students can be introduced to the idea that gear trains transfer force in other directions (e.g., right angles).

**4 Exploring pulley systems**

**Broom pulleys**

Students are introduced to pulley concepts by building a pulley system using a broom and rope (view this activity on video at www.csiro.au/scope/clips/e71c01.htm). This activity involves children holding brooms (act as the pulleys) opposite each other at 2 metres apart. Tie a rope around one broom (first broom), now pull the rope hard while the person with the broom provides resistance. How much force is required? Wrap the rope around the second broom so that the rope comes back towards the first broom (the second broom should try to stay stationary), now pull and feel whether this changes the amount of effort needed to move the fixed broom. How much rope is pulled through to get the fixed broom to move? Children can experiment by comparing how often the rope is wrapped around the brooms (number of pulleys) with the effort required and the length of rope pulled through.
Students should be able to:
• recognise that pulleys make things easier to lift or move
• recognise that more than one pulley will decrease the effort required by spreading the load over a greater distance. Two pulleys reduce the load by half, three pulleys by one-third.

Pulley challenge
Students can use a variety of materials to find the easiest way to lift heavy objects, or to transfer an object from one place to another. Students can be given a challenge, such as to move a heavy object from one side of a canyon to another (between tables), or to lift the object from the floor onto a table. Children can be given a variety of objects, such as tables that can be upturned to use the legs as anchorage points, a load (such as a small bucket of sand or weights in a rack), pulleys (single and double), rope or strong twine, and string and sticky tape for attachment purposes. Ask students to examine the materials first and discuss how they could be used as fixed or moving structures. As an added challenge, students may be required to shift a large weight with a smaller weight.

Extension
Students can begin to explore the direct relationship between increases in the number of pulleys and the length of string being pulled and the effort required. ‘Explorable’ questions can be developed to guide this.

5 Exploring inclined planes

Measuring the force required to shift a load up a ramp
In this activity, children explore the usefulness of ramps in lifting loads. Ramps can be constructed out of any flat, stiff object, such as wood, a table or a book raised at one end. Children pull objects up a ramp and measure the amount of force required using either a force meter or by measuring the stretch of an elastic band attached to some sort of weight. By adjusting the height and length of the ramp, students can see the change in force required to lift a load.

Students should be able to:
• recognise that less effort is required to push or pull a load up a ramp than to lift it straight up
• identify that the longer the ramp (and therefore a lower gradient slope), the less effort is required to move an object up to a particular height.

Looking at screws
This activity allows students to construct screws, reinforcing the idea that screws are inclined planes wrapped around a shaft. This activity would come after students have an understanding of the mechanical advantage of inclined planes when pushing or pulling an object upwards, but that greater distance is required. Students can be encouraged to think about how we can arrange a ramp so that it takes up less space but still has the necessary length; for example, how ramps would be used to get to the top of a three-storey building, alluding to spiral staircases. How are screws the same as spiral staircases? In order for students to see the inclined plane in a screw, encourage them to change the way a two-dimensional paper ramp (a right-angled triangular piece of paper) looks by twisting it around a pencil, starting with the shorter vertical edge against the pencil. Have students do this with 2-D paper ramps at
different angles in order to see how screws are formed, comparing the number of turns and distance travelled, and drawing conclusions about the effect of each option. If possible, have them experiment with real screws of different sizes, screwing them into a block of wood: Does the distance between the grooves make a difference to the amount of effort required?

**Extension**

Students can be introduced to the idea that a decrease in the length of the ramp also means an increase in ‘incline’ or ‘angle’. Students may investigate the effect that friction has on the effort required to move an object, using ‘explorable’ questions such as: What does changing the surface of the ramp do to the amount of force required to lift an object along it?

**6 Representing force in simple machines**

As an ‘explain’ activity, this would involve classroom discussion about what is actually happening in the simple machines that students have experienced during the ‘explore’ lessons. The emphasis here is on encouraging students to think about where force is being applied, where the load is, the motion that results from the force, and how the machine has modified the force; that is, the mechanical advantage. Students can be encouraged to think about how they would ‘represent’ force (usually a push or pull, or a twist in the case of handles), load, motion and mechanical advantage on a diagram. It is better to begin with students using their own representations before the scientific convention of arrows is introduced. Students can then use arrows to represent the direction and size of the force applied, and the direction and speed of the resultant motion. (Refer to the earlier section on representing forces in this chapter, ‘Acting on playdough’ on p. 100, for a possible sequence for this.) Remembering the activities from previous lessons, use two common simple machines to draw annotated pictures, using arrows to represent force and movement.

**7 Analysis of simple machines in videos and pictures**

In this activity, students view and analyse DVDs/videos and pictures of simple machines. This activity can be constructed in many ways depending on its purpose and placement in the learning sequence. If used as an ‘engage’ activity, the focus is on introducing everyday examples of simple machines, or setting the scene for a problem-based sequence (as in unit 2), as well as for motivational purposes. If used during the ‘explain’ phase, students can be encouraged to apply their new knowledge to the events in the video; for example, students or the teacher could choose sequences in a Honda Accord commercial (see www.youtube.com/watch?v=uyN9yOBEMqQ) where simple machines are used, demonstrating students’ ability to identify and classify different machines. Students could also describe the mechanical advantage of each. Used at the beginning of an ‘elaborate’ lesson, as in unit 1, a ‘Rube Goldberg machine’ video (see the next section) or the *Wallace & Grommit: the Curse of the Were-Rabbit* trailer (see http://trailers.apple.com/trailers/dreamworks/wallace_and_gromit) can provide stimulus for student designs. There are many examples of these on YouTube.

**8 Design challenges**

This activity integrates with the design–make–appraise strand associated with the various design technology curriculum frameworks. All three units culminate in a design challenge, mainly because the topic, simple machines, lends itself to integrating technology as an application of scientific principles. Technology activities can work well as summative assessment tasks, so long as the
assessment focuses on how students apply the scientific principles of simple machines. Do students understand how the design features of the machines change the direction of the force, increase or reduce the speed of the force, or magnify the strength of the force?

For any design challenge where construction is involved, students engage with three processes: designing, making and appraising, the order of which may change depending on the purpose of the activity (Fleer and Jane 2004). Students may be encouraged to: design first, make the item according to the design and write about it, then appraise with the teacher in terms of improvements or changes that could be made and add this to the written explanation (DMA); make and write about the item, appraise with the teacher, and develop the design (MAD); or play with and appraise the materials, design the item, and make and evaluate and write about it (ADM).

**Designing a Rube Goldberg (or chain reaction) machine**

A Rube Goldberg machine is an overly complex and confusing machine that is designed to perform a very simple task. Rube Goldberg was an American cartoonist who was well known for depicting complex devices that accomplished something simple through complex means, often through a chain reaction sequence beginning with a stimulus and ending in the desired action. The design only, or design and construction, of such a machine could be done individually, in groups or as a class. Computer animation software can also be used to create or manipulate machines, then observe the effects; for example, Pivot Stickfigure Animator (see http://pivot-stickfigure-animator.en.softonic.com) and Crayon Physics Deluxe (see www.crayonphysics.com). Potential contexts for the construction are:

- a class project, where small groups design and construct separate sections of a large machine that utilises the whole classroom
- as a board game, similar to the Mouse Trap board game; see Barlow, Kramer and Glass (1963)
- for a particular action, such as opening the door or cleaning the whiteboard.

**Designing playground or game equipment**

Students can design playground or game equipment that incorporates levers and inclined planes (as in unit 2). Students develop annotated diagrams within a storyboard to show how the equipment is used, where the levers and inclined planes are, and how they modify forces.

**Designing a cart**

Children can design carts (as in unit 3) for a particular purpose, such as for running quickly down a slope or travelling as far as possible in a straight line across the floor. They are asked to solve the problem of how the wheel and axle are attached so that the wheels go around. This can be an individual or paired activity, according to children’s needs. Different versions of the activity are discussed in the online Appendix 3.3.

Provide assorted materials – boxes, containers, card, tape, string, scissors, straws, wooden skewers, container lids, pieces of polystyrene, Blu-Tack and plasticine.

Older children can be asked to make a drawing of their design first. This can then be modified after the construction and a report written on why modifications had to be made. The task can be focused on how well the vehicle rolls down a ramp or along the ground.
Activity 3.9 Cart construction activities

- Read the online Appendix 3.3 and discuss the following issues in light of the vignettes and discussion.
  - The materials children are given have a big impact on the style of cart they construct. A limited range of materials limits the range of possible solutions. Materials that are difficult to work with can not only frustrate children, but can also encourage significant problem-solving behaviours. What range of materials would be appropriate for cart construction? Why?
  - A teacher should encourage a range of solutions to design problems, but should make sure each child constructs a successful cart. This may involve suggesting specific solutions or pointing out problems before they happen. If children cannot make a cart, they cannot move forward to considering aspects of motion. How appropriate would it be to give children worksheets showing how a cart can be made?
  - Design drawings should be a part of any construction activity. Usually, though, the design is worked out as the child grapples with the materials. Drawings can often be more useful as part of reports written after the construction phase. Do you agree with this view? What should such a drawing show?
  - In any sort of learning activity, and particularly with individual investigative or construction work, the purpose of the child and that of the teacher can be very different. What aspects of children’s purposes in constructing carts might interfere with learning about wheels and motion?
  - An English study identified measurement as being an undeveloped science skill in primary school, despite emphasis on processes in the English national curriculum. Children do not tend to undertake controlled measurements or understand their purpose. How is this best done for cart construction?

- Construct a land yacht that will move in a controlled manner – driven by the breeze from a fan – across the floor. Compare different models of land yachts and draw up a list of statements about the effect of features such as the length of the axles, the materials used, the size and position of the sail and the wheel–axle arrangement. Plan and conduct a controlled investigation to verify one of these statements.

- Locate the statements in your State/Territory or the Australian science curriculum related to measurement and investigation. Discuss the sorts of expectations and responses to activities involving carts that might illustrate each of the outcome statements at the different levels.

Activity 3.10 Developing science concepts through construction activities

Cart or machine construction is essentially a technology activity that can take place without any reference to science concepts. At what point does technological knowledge become scientific knowledge? A class of children has successfully built a variety of carts. What activities or questioning strategies might be used during and after the construction to
extend children’s understandings about force, energy and motion?
   From your science syllabus/standards document, locate the science outcome statements relevant to motion and construction activities. What sort of things might children do, say or write that would illustrate these outcomes? Use activities from this chapter to generate examples of children’s responses that would illustrate the range of outcomes.

9 Classification and differentiation activities
When used in the ‘explain’ phase, these activities enable students to recall, reorder, consolidate, build on and transform the knowledge and experiences gained through the ‘explore’ activities. The following activities could be completed in sequence or developed further individually. Usually, a discussion about what has occurred up until now (e.g., types of simple machines, the examples already seen, what the machines did) would precede the activities.

For a classification activity, as a class, use texts that describe the key ideas of levers and ramps (either teacher-prepared or generated in class) to classify a selection of common household simple machines.

For a differentiation activity, take two items and develop a Venn diagram of the similarities and differences in their uses and how they make life easier. Focus on how the machine in question is designed to change the direction of force applied, increase or reduce the speed of the force applied, or magnify the strength of the force applied.

Activity 3.11 ‘Explaining’ force principles through representation
There are two approaches to the ‘explain’ phase in units 1 and 2. Unit 1 focuses on how to represent force principles in diagrams, while unit 2 uses classification activities and Venn diagrams to differentiate between the different principles. In this activity, you are asked to think about, firstly, how you would represent your own understandings of simple machines, and secondly, how explanations might be generated flowing from the previous exploratory activities.

- For each type of machine, develop a representation of how the machine works to secure mechanical advantage. To do this, you might use a combination of: drawings with force representations, annotated comments, mathematical expressions, role-plays, time sequence drawings or annotated photographs.
- Work out a way of representing (such as with graphs, annotated diagrams, tables, Venn diagrams or concept maps) the different sorts of simple machines and examples of each.
- Represent, perhaps using a table, Venn diagram or other classification device, the key principles of force alteration involved in a range of simple machines. You might like to think about how an interactive whiteboard might provide a flexible way of grouping a variety of machines under different principles.
- Discuss these representations with colleagues. What are the various ways in which knowledge of simple machines can be effectively communicated?
- Develop, in your group, a strategy for scaffolding children’s ideas that emerge through the exploratory activities, to generate representations that constitute productive explanations of simple machine principles.
10 The language of wheels: tricycles and pushers

This activity is intended to introduce children to the vocabulary and basic concepts associated with wheels and motion and to give them experience in observing similarities and differences. This can be extended into a substantial language activity.

- Bring a pusher (or pram) and a tricycle into the classroom and seat the children around them so that they can look at the items from different angles. You may like to put the vehicles on a table so that the children can look up at them from underneath.
- Ask the children to look at them close up and from a distance.
- Make a class list of the parts that children notice: one list for the pusher and one for the tricycle.
- Look for things that the pusher has in common with the tricycle.
- Discuss the differences between them.
- Ask the children for their ideas on what specific parts are used for.
- Help them to decide how the pusher and tricycle would be made to move or stop.

For older children, a discussion of where the energy comes from and what energy is will be appropriate (see Chapter 5).

11 Role-modelling wheels

This activity helps children to get a feel for how the roundness of wheels helps with motion.

- Use the classroom, corridor or mats outside for rolling activities.
- Ask individual children to roll along the ground.
- Talk about how they will get going.
- Discuss how they will stop, what keeps them rolling and which shape is best for keeping going. Observe these efforts closely.
- Invite suggestions from children about different shapes for rolling.
- Ask the rollers to talk about the differences they felt in one complete roll.
- Group the children into threes or fours.
- Experiment with rolling: ask one group member to start off the roller; have another person stop the roller in three ways:
  - by remaining still so that the roller experiences the force of a stationary object
  - by interrupting the roll by some movement so that the roller experiences the force of a brake
  - by rolling over a cushion.
- Change around so that everyone has a turn in each role.
- If you have access to a slope, have the children compare rolling up and down and stopping on a slope so that they experience the difference that a bit of falling makes to the rolling.
- Compare the different need for pushing and pulling.
- Discuss the differences in their experiences and link to the pusher and the trike in terms of shapes, brakes, getting going and so on.

Prep children could be asked to make wheels from playdough. Their wheels could be spherical, flat-like pancakes or long and thin. What is a wheel? Are all round things wheels? Could an apple or orange be made into a wheel?
12 Exploring the science of rolling down slopes: ramproll

This activity is very open-ended and exploratory and can be used to work with children on measurement principles, experimental design and analysis using tables or other means. It is a classic engagement with ideas and evidence activity.

**Jam jar POE**

Take two identical jars, one full of jam (or honey or even plasticine will do) and the other empty. Predict which, when rolled down a slope, will go furthest along the carpet (see Figure 3.4 for the arrangement). Discuss your prediction in a group. Try this so that you are confident you have a clear result. Discuss what you think is happening. Is the difference due to the speed they roll down the slope?

**FIGURE 3.4 Ramproll**

*How far does it roll?*

Work with a number of cylindrical rollers (e.g., various-sized batteries, plastic pipes, cardboard tubes, steel rods, pens and wooden rods). Your task is to work out what makes a difference to how far they can roll along the floor.

Try each roller, rolling it down the slope (a book will do) and writing in the table how far it goes. Measure each distance twice to check.

*How fast does it roll?*

Compare a number of rollers, two at a time, to determine the order of speed with which they roll down a ramp. Try a series of cylinders and balls, hollow and solid, light and heavy. Line them up in order of speed. What patterns can you see?

**Activity 3.12 Exploring rolling**

*The science underlying the ramproll activity*

Hollow things tend to roll further than solid things because they have less weight for the same diameter; this reduces friction. If the friction was the same, they would all go the same distance as the energy gained rolling down the slope is used up. Paradoxically, hollow things tend to roll slower down the slope because more energy goes into the
13 Excursion to a science resource centre
Science resource centres include zoos, aquariums, museums, science activity centres (such as Questacon in Canberra or Scienceworks in Melbourne), and environmental centres or field sites of various types. Taking children to a science resource centre can be highly motivating and can prompt significant learning through interaction with quality exhibits and activities and expert interpreters. Such excursions can be used at various points in a unit sequence: at the beginning or early in the sequence to promote interest in the topic and to provide a reference point for later experiences; at the 'explain' stage to allow students to build explanations based on prior experiences in collaboration with information from the centre exhibits; or as a finale to the children's study.

In one implementation of unit 3, the children attended Scienceworks, which had a display on 'wheels' at the time that focused on the technology of wheel design as it had developed over time. Children explored a range of wheeled vehicles and played with wheeled toys, role-modelled wheels, and were exposed to the language of wheels. They looked at old stagecoaches, penny-farthing bicycles and a range of historic and modern vehicles. A sheet of prompt questions was used by accompanying parents to elicit ideas and explore such things as wheel size, axle arrangements, brakes and gearing. Questioning approaches were modelled by the teacher at the first exhibit, a Cobb & Co. coach. This use of the centre was consistent with research into the role of informal settings in science learning.
TEACHING PRIMARY SCIENCE CONSTRUCTIVELY

Studies of informal learning explore different sources of public knowledge about science. These influence the ideas children bring with them to the classroom. Television, newspapers and magazines, the Internet and other electronic media, and experiences within the family, all form part of the science learning environment. Rennie (2007) points out that, while education tends to be narrowly equated with what goes on in schools, museums and resource centres provide an alternative informal setting for science learning.

Griffin (1994) argues that visits to informal science education settings should reflect what we know about the way in which students learn science, about exemplary teaching practices and family group learning behaviours in informal settings, rather than principally be the worksheet-dominated visits that tend to be the norm for schools. It is quite common in museums to see schoolchildren sitting in the middle of a display hall collaboratively filling in worksheets using observations made by only a few children. Griffin argues for inclusive, learner-centred approaches to museum visits and offers a set of guidelines:

- Embed the museum visit firmly in the classroom-based learning unit.
- Use a learner-centred approach in which the students are finding the answers to their own questions rather than their teachers’ or the museum’s questions.
- Encourage students to gather questions while at the museum as well as finding answers.
- Apply learning methods used by informal groups, such as an orientation period and decreasing detailed examination of exhibits over the visit.
- Develop strategies and approaches to learning that recognise and complement the particular learning environment.
- Recognise that students and teachers need to adapt to and learn to use this different type of learning setting.
- Create a close link between museum and school learning, but recognise the different roles of each.

Activity 3.13 Planning for a visit to a science centre or museum

- Carry out a Web search of a museum or science resource centre to identify exhibits that relate to simple machines (for instance, Melbourne’s Scienceworks has machines as part of its Nitty Gritty Super City exhibit (see http://museumvictoria.com.au/scienceworks/education/education-kits/nitty-gritty). Evaluate any information kits or teacher or student resources associated with the exhibit.
- How might you embed a visit to the centre as part of a learning sequence focused on force and motion? Devise some pre- and post-visit classroom activities that would maximise children’s learning from a visit to the centre.
- Generate a range of questions that children could explore during the visit or that might arise out of the visit.

Activity 3.14 Designing learning sequences

- Use activities relating to force to plan five consecutive lessons according to the 5E framework for a year 3 or 4 class. Select activities from earlier in this chapter, from Appendix 3.1 for assessment strategies (see p. 140), or from others that you know. You might like to base your sequence on a
CHAPTER 3 Movement and force

Science as a human endeavour

Several sections of this chapter have dealt with the human dimensions of force and machines. This was particularly explicit in the simple machines section, which is all about how machines are designed to alter forces to allow us to do things we could not otherwise do, such as crack nuts, move large weights or even lift our arms. The section on the history of wheels and transport shows clearly the wider social impact of force and machines. Even with only a basic understanding of force and its application to motion, the human dimensions are clear. In teaching about force, we can appeal to a wealth of everyday experiences to give a sense of the embodied nature of forces – the way we can ‘feel’ forces in a diagram or description of how hard we have to push a trolley, how gravity acts, or how air takes hold of a kite. We can explore our bodies to find examples of the application of forces – the lever action of the forearm or the structural properties of the skeleton.

Thus, the science of force and motion can be related to personal experience to bring relevance. It can also be related to the story of human use and manipulation of force through

Activity 3.15 Planning assessment for learning about simple machines

- As explained earlier, three types of assessment are diagnostic, formative and summative. Each is appropriate at different stages of a unit of work. For one of the three units of work described in Table 3.3 (see p. 125), identify which tasks may be used for diagnostic, formative and summative purposes. Discuss and report on other ways you could explicitly build assessment into the sequence.
- Looking at the earlier section on constructing assessment rubrics (see the section ‘An assessment rubric for movement and force’ on p. 113), develop an assessment rubric for one of the assessment tasks you proposed. Be sure to carefully consider what the task allows you to see about students’ science knowledge, skills and attitudes. Are there other criteria that you regard as worth assessing?
- Look at your State/Territory’s science curriculum or the curriculum. Map your criteria with the curriculum standards or outcomes.

- Design a worksheet that could be completed before, during and/or after one of the ‘explore’ phase activities in the above sequence. Make sure the worksheet is structured in such a way that directions for students’ observations and thinking are linked to the intended learning outcomes of the activity. Considering that this is an ‘explore’ phase activity, how much direction should the worksheet give students in their ‘explorations’? As an added challenge, embed in the worksheet opportunities for student inquiry where students construct and investigate ‘explorable’ questions that might arise out of the activity.

- Provide a rationale for each part of the sequence and for the assessment strategy used.
- Share your sequence with another group – How are they different and similar in how the activities are sequenced and in the rationales used?

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- Share your sequence with another group – How are they different and similar in how the activities are sequenced and in the rationales used?
machines. In relation to the world of work, engineers design machines to make our lives easier, and for every machine there will be a host of professions that use them.

There are many activities we can include in a unit on force that would link the topic with human use and human interest:

• Children could research and report on machines throughout history, such as waterwheels, catapults, steam trains or chariots.
• Children could write letters to manufacturers or engineering organisations asking questions about machine design, thus encouraging questioning skills and supporting literacy practices.
• Children could create a time line of machines throughout history, or of the development of the bicycle or gears.
• The human dimension of the topic could underpin further investigations based on the conceptual principles of a machines unit. The question ‘What machines are seen in …?’ could be the underlying question for surveys and transport studies, from simple ways of categorising machines (tricycles, bobcats, gymnasium equipment, kitchen implements) according to their uses, to more complex issues of engineering works and community life.
• Studying means of transport where wheels would not be useful could enlarge the children’s view of the world.
• Technological design activities where machines were invented for particular human use would open up discussion of science and human needs, and potentially of ethics and values associated with science and technology.
• There could be interesting connections made between the topic of machines and design technology, with children investigating and building the wheels used in entertainment – for example, unicycles, Ferris wheels, merry-go-rounds – or simple machines used in hunting and gathering societies, with the study of materials and systems involved developing into a connected topic.
• An understanding of community life and those members who use simple machines as part of their employment or their means of movement could be a rich source of new information and insight. This might include interviewing people who use wheelchairs, or potters, gardeners with shovels and wheelbarrows, and tyre repairers. The rights and responsibilities of being a community member could be explored through services for other people and the different occupations of people in the neighbourhood.

Activity 3.16 Science as a human endeavour

• Review the discussion about forces and simple machines in this chapter and list the variety of ways these topics link with a ‘science as a human endeavour’ strand, as in the Australian science curriculum (ACARA 2010). These could refer to human use, the impact of forces and machines on human culture, science professions that involve their development or use, and values and ethical issues associated with the topic.
• Revisit the curriculum sequences you planned in Activity 3.14 (see p. 136). Which activities add to students’ understandings of science as a human endeavour?
• Create a list of ways in which this strand could be more explicitly represented in the sequence, including assessment.
Summary

In this chapter, the authors have drawn on various aspects of their teaching and research to raise some issues about the teaching and learning of movement and force and issues to do with teaching and learning, assessment and schooling more generally. These include:

- the way children’s conceptions of movement and force relate to scientific conceptions
- the role of exploratory activities in conceptual learning
- approaches to assessment of learning
- the role of literacy practices in learning science
- scientists’ and children’s conceptions of simple machines
- planning simple machine sequences using the 5E framework
- the management of, and the learning that arises out of, simple machine activities
- science as a human endeavour in the context of force and motion.

Concepts and understandings for primary teachers

Movement and force are areas in which many informal, non-scientific ideas are held by children and adults. The major scientific understandings related to movement and force are discussed below as a summary of much of the discussion in this chapter.

On forces and motion

- A force can be thought of as a push or pull, but essentially, it is an effect on an object that causes a change in its motion: speeding up, slowing down or changing direction.
- Forces are an external influence on an object, such as a hit from a bat or a pull from the Earth’s gravity, and are not something the object possesses within it. Thus, when a sliding object slows down, or when a golf ball falls to Earth, it is not because of an initial force being used up, but because of friction acting in the first case, and gravity in the second.
- Kinetic energy (the energy associated with motion) and momentum, on the other hand, are associated with a moving object and will reduce as the object slows.
- Friction is a pervasive force that causes things to slow down, but it is also the force that helps us accelerate when we are running or riding a bicycle.
- Forces come in pairs, so if an object such as your hand exerts a force to hold up a brick, the brick will exert a force back on your hand that is equal but opposite in direction. Action–reaction force pairs always act on different objects.

- Common forces include contact forces (physical pushes, support or traction from the ground, friction, air or water resistance opposing motion, force from wind) and field forces (gravity, magnetic forces, electric field forces).

- Forces will add together to affect objects. Forces can oppose each other, such as the upward force from the ground opposing gravity when we are standing. They can also add, such as when two people pull a cart along together.

- Situations of balance (such as for mobiles or seesaws) and twisting can be understood as due to forces acting off-centre, not through the fulcrum or rotation point.

- An object rolling down a slope will be accelerated by the force of gravity (its motion is somewhat akin to a slow-motion freefall).

On flight and falling

- Falling things are subject to a gravitational (weight) force down and an opposing force of air resistance up.
- Except for very spread-out objects, such as pieces of paper or feathers, for which the air resistance can be as large as the weight, heavy things do not fall faster (that is, they do not accelerate more) than lighter things. Thus, a tennis ball and a cricket ball will fall with essentially the same acceleration (at least over short distances).

- Nor do heavy things roll faster down slopes, but there are effects on speed of rolling that are due to shape (for example, hollowness, spheres versus cylinders).
• Planes stay in the air because of the greater force of air on the underside of their wings compared to the top side. This is due to the shape of the wings and airflow patterns.

On simple machines
• Simple machines are devices for altering the nature and effectiveness of a force to better get jobs done.
• Levers are usually classified as first-, second- or third-class according to the relationship between the effort, load and fulcrum. For a lever, there is a simple relationship between the output load force and the effort, linked to the relative distance of these from the fulcrum.

• Screws and wedges are specialised examples of the inclined plane, which magnifies the size of a force and changes the direction.
• Gears and gear chains change the speed and direction of motion as well as the size of forces.
• Pulleys change the direction of a force and in cases of multiple pulleys are useful in increasing the magnitude of a force.
• Wheels are devices for reducing the force of friction. They do this since, at the wheel’s contact point with the ground, it does not slide. Large-diameter wheels (or rollers) tend to reduce the friction associated with rough surfaces.

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Appendices
In these appendices you will find material related to movement and force that you should refer to when reading Chapter 3. These appendices can be found on the student companion website (www.cengage.com.au/skamp4e). Appendix 3.1 is included in full below.

Appendix 3.1 Assessment strategies

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<th>DIAGNOSTIC</th>
<th>FORMATIVE</th>
<th>SUMMATIVE</th>
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<tr>
<td>• Graphic organisers – concept maps, mind maps</td>
<td>• Concept maps – the idea is to have an assessment piece that incorporates the possibility of reviewing and revising and resubmitting</td>
<td>• End-of-topic tests</td>
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<td>• Journal entries</td>
<td>• K and W of KWL charts</td>
<td>• Repeated probing activity from beginning</td>
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<td>• Pre-tests</td>
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Appendix 3.2 A critique of the 5E learning models
This online appendix provides a critical appraisal of the 5E instructional strategy, identifying its strengths and limitations when applied to lesson and unit planning.

Appendix 3.3 Cart construction and thinking technologically
In following the sequence described as unit 3, a number of cart-construction classes were observed and these observations form the basis of the case study in this online appendix.

References
TEACHING PRIMARY SCIENCE CONSTRUCTIVELY


Children’s books about machines and wheels


