EDITED BY KARL MATON,
J. R. MARTIN AND Y. J. DORAN

LCTC

TEACHING SCIENCE

Knowledge, Language, Pedagogy

Legitimation Code Theory

ROUTLEDGE

4

ANIMATING SCIENCE

Activating the affordances of multimedia in teaching

Karl Maton and Sarah K. Howard

Integration is more than selection; affordances are more than interactions.

Introduction

Multimedia objects that combine diverse visual and audio elements – text, pictures, moving images, speech, sounds, etc. – are a common feature in classrooms (Li *et al.* 2019). Increased access to the Internet and rapid growth in online 'educational' materials has made such multimedia as animations evermore available to teachers as classroom resources (Berney and Bétrancourt 2016). These are particularly of interest to science education as ways of displaying complex explanations (Ploetzner and Lowe 2012). Moreover, studies claim a 'multimedia effect' whereby students learn better through words and pictures together (Mayer 2003). However, not all multimedia are created equal – some are more suited to classroom practice than others. Moreover, even if designed for a particular curriculum, a multimedia object is unlikely to match the needs of a specific task in a specific lesson in a specific classroom. Thus, questions of how teachers integrate such ready-made objects into classroom practice are increasingly significant (e.g. Jenkinson 2018). Yet, these questions are not the concern of most education research into multimedia. Instead, the principal concern is exploring *cognitive* processes of *student learning* and generating principles for *designing* multimedia that support those processes (e.g. Mayer 2014b, Mutlu-Bayraktar *et al.* 2019). Questions of how *pedagogic* practices by *teachers* support *integrating* multimedia into classroom tasks are marginal. This chapter contributes to foregrounding and addressing these questions in the context of science teaching.

We begin by arguing that to understand integration requires bringing into the picture both teaching and the knowledge practices being taught. To begin meeting this need we draw on the notion of 'affordances' (e.g. Bower 2017), which highlights that technology such as multimedia objects differ in their abilities to meet the demands of different classroom tasks. However, we argue that current uses of 'affordances' are too limited. Studies overwhelmingly examine affordances for interactions, especially among students, and ignore affordances for teaching and learning specific knowledge practices. To address this 'knowledge-blindness' (Howard and Maton 2011, 2013), we introduce concepts from the Autonomy dimension of Legitimation Code Theory. These concepts reveal one aspect of the knowledge practices expressed by resources and their *epistemic affordances* for teaching and learning. Specifically, *positional autonomy* conceptualizes relations between the content required by a task and that expressed by a resource, *relational autonomy* conceptualizes relations between the purposes for which that content is needed by a task and those for which it is used in a resource, and *target* places the specificities of each classroom task at the centre of analyzing these two relations. Enacting these concepts, we explore both the affordances of multimedia objects (and other resources) for building knowledge in tasks and how teachers select and activate those epistemic affordances in classroom practice.

Specifically, we conduct two in-depth analyses of integrating multimedia in secondary school science classrooms. We focus on the use of animations, a central concern of multimedia research (Li *et al.* 2019). In both examples, a science teacher selects an animation whose affordances are well suited to their task, both in terms of interactions enabled and knowledge practices expressed. However, while one teacher activates its epistemic affordances, the other fails to do so. These analyses illustrate that integration does not end with selection and that *pedagogic work* by teachers is required to activate the epistemic affordances of resources. In short, they show how understanding success in teaching science with multimedia requires seeing not only the multimedia but also the teaching practice and the science knowledge being taught.

Integrating multimedia into teaching

The cognitive–learning–design axis

Multimedia combine words (spoken or text) and pictures (such as still or moving images). It is widely acknowledged that multimedia resources are becoming more accessible for education (Berney and Bétrancourt 2016). How, then, can teachers best integrate such multimedia objects as animations into classroom practice to support teaching science? This is our focus in this chapter. However, this is not the focus of the vast majority of research into multimedia (see Li *et al.* 2019). Most studies focus on learning rather than teaching, designing rather than integrating multimedia, and computer-based contexts rather than classrooms (e.g. Mayer 2014b). This is not to dismiss this body of work but rather to highlight that dominant approaches to the educational potential of multimedia are not concerned with integration.

Instead the focus of most research lies on a cognitive–learning–design axis. Commonly used models, such as 'cognitive theory of multimedia learning' (Mayer 2014a) and 'cognitive load theory' (Sweller *et al.* 2019), examine such issues as how the brain processes information, audio and visual channels, and kinds of memory. Implications are drawn for how to combine visual and auditory information in order to, for example, manage 'cognitive load' (e.g. Mayer and Moreno, 2003). This provides insights into design principles, such as the 'spatial congruity principle' that text and visual content should be proximate (Mayer and Fiorella 2014). However, this cognitive–learning–design focus obscures integration in two principal ways. First, teachers and teaching are treated as if limited to designing 'environments' or selecting resources that meet design principles. This leaves aside almost all real-world classroom pedagogy. Second, the forms taken by the knowledge practices to be taught and learned are absent or reduced to the status of 'topic', 'subject matter' or 'information'. This ignores that learning involves learning something and that the forms taken by the knowledge practices expressed by multimedia may affect their integration into teaching and learning of that something. Thus, while valuable for developing generic principles for designing multimedia, these frameworks are not well suited to questions of integrating multimedia into teaching specific knowledge. We thus need to bring teaching and knowledge into the picture.

The affordances of 'affordances'

A fruitful starting point is the notion of 'affordances' which is typically used in education research to explore the capacities of technologies for enabling actions (Bower 2008, Hammond 2010, Antonenko *et al.* 2017). For classroom practices, this is to say that a resource may be more suited to some tasks than others. Affordance 'frameworks' list 'abilities' of technology; Bower (2017), for example, includes read-ability, write-ability, playback-ability, share-ability, among others. The aim is for 'designers' of 'learning environments' to select resources that offer the abilities required by tasks. The notion of 'affordance' thus offers the potential to foreground classroom tasks and so integration.

However, this affordance of 'affordance' is often not activated by research, which is animated by the cognitive–learning–design axis. For example, the notion is said to help show 'how tools interplay with *cognition* and hence how to best *design* educational systems that meet the *learning* requirements of tasks' (Bower 2008: 4; emphases added). Studies also share the blind spots of teaching and knowledge practices. Consider the proclaimed affordances of 'affordance'. Hammond (2010: 211), for example, states: 'This is its major value as a concept: it is not the tool, it is not the person, it is the interaction of tool and person'. Focusing on interactions that a 'tool' enables, both between 'tool and person' and among people, is indeed the principle way that 'affordances' is used. However, the people studied are only learners and not teachers, the 'interaction' is only learning and not teaching, and the role played by what is to be taught and learned through the interaction is absent. This focus on student interactions is underscored by the huge field of 'Computer-Supported Collaborative Learning', whose gravitational weight pulls attention away from real-world classrooms and most forms of pedagogy. For example, affordances are often clustered together as supporting, for example, 'static/instructive' or 'collaborative/

productive' interactions (Bower 2017), where the latter focus on student interactions garners most research.

In short, existing research focuses on what we shall term 'interactive affordances'.[1] This underestimates the affordances of the notion as an animating metaphor for research. To help examine integration, we shall focus on *epistemic affordances* – how knowledge practices expressed by a resource offer opportunities for teaching and learning – and analyze how teachers can activate those epistemic affordances in teaching science.[2] To do so, we draw on Legitimation Code Theory.

Legitimation Code Theory: Autonomy

Legitimation Code Theory (LCT) is a framework for researching and shaping all kinds of practice (Maton 2014) but has proven particularly valuable for exploring knowledge practices (e.g. Howard and Maton 2011). LCT is also widely enacted to analyze and inform teaching.[3] The framework comprises several *dimensions* that reveal different aspects to knowledge practices. For example, concepts from the Semantics dimension (Maton 2020) can, among other things, reveal how the context-dependence of meanings expressed by a resource can support a task, such as affording the desired degree of concreteness.[4] Concepts from the Specialization dimension (Maton 2014) can reveal, among other things, how the representational fidelity of images afford possibilities for teaching and learning specific ideas. Indeed, LCT affords far more possibilities for analysis than can be enumerated here. Thus, we shall focus on the broader issue of the content and purpose of knowledge practices expressed by resources. We draw on the Autonomy dimension, which is particularly suited to exploring integration (Maton and Howard 2018, chapter 2 of this volume).

Autonomy

The dimension of Autonomy explores what makes practices distinctive. It begins from the simple premise that any set of practices comprises constituents that are related together in particular ways. Autonomy explores how practices establish different degrees of insulation around their constituents and around the ways they are related together. Here we can describe constituents as the *content* of practices and how they are related together as the *purpose* to which they are put. We can then distinguish:

- *positional autonomy* (PA) between content within a context or category and content from other contexts or categories; and
- *relational autonomy* (RA) between the purposes to which content is put within a context or category and purposes from other contexts or categories.

Each may be stronger or weaker along a continuum of strengths. The stronger the positional autonomy, the more insulated are contents from those of other contexts or categories; and the stronger the relational autonomy, the more insulated are purposes from those of other contexts or categories.

TABLE 4.1 Generic translation device, first two levels (adapted from Maton and Howard 2018: 10)

PA/RA	*1st level*	*PA/RA*	*2nd level*
stronger	*target*	++	*core*
		+	*ancillary*
weaker	*non-target*	–	*associated*
		– –	*unassociated*

The 'contexts or categories' in these definitions are held open to embrace the manifold diversity of practices. To enact the concepts, one needs to develop *translation devices* that show how they are realized within specific problem-situations (Maton and Chen 2016). As shown in Table 4.1, Autonomy offers a *generic translation device* as a first step. This device is activated by asking: what contents and purposes are considered constitutive of *this* context or category, here, in *this* space and time, for *these* actors? This gives a 'target' against which to compare practices. If their contents are from within this target, they embody stronger positional autonomy, and if from elsewhere, they embody weaker positional autonomy; and the same holds for purposes and strengths of relational autonomy. A more fine-grained analysis may then ask: what of the target is considered *core* and what *ancillary,* and what of other contents and purposes are considered *associated* with or *unassociated* from the target? As Table 4.1 shows, this generates four strengths for positional autonomy and for relational autonomy.

This device is, though, still 'generic'. To translate to specific data we must decide whose target to examine and at what level. First, a target is always *someone's* conception of what makes a context or category distinctive; whose target is chosen to ground analysis depends on the problem-situation. We shall analyze two examples of teaching, so we focus on each teacher's targets (and use such possessives throughout the chapter).[5] Second, targets can describe 'contexts or categories' of all kinds. For example, in our analysis of integrating mathematics into science (chapter 2, this volume), each teacher's target is a syllabus stage and their core target is a unit of study. These broad categories capture relations between two subject areas across whole lessons. Here our questions are more fine-grained: how a specific multimedia object relates to specific tasks in specific lessons. Thus, we analyze each teacher's target as the lesson and their core target as the task in that lesson. Using the translation device of Table 4.2, we can revisit the concepts to state that here:

- strength of *positional autonomy* conceptualizes whether contents expressed by a multimedia object match the teacher's core target content for a task (PA++), match their target content for the wider lesson (PA+), come from beyond the lesson (PA–) or come from beyond the unit (PA– –); and

TABLE 4.2 Translation device for analysis in this chapter

PA/RA	*1st level*	*In this analysis:*	*2nd level*	*In this analysis:*
++	***target***	lesson	***core***	task
+			***ancillary***	rest of lesson
–	***non-target***	other contents or purposes	***associated***	other unit lessons or related to task
– –			***unassociated***	knowledge from beyond unit

- strength of *relational autonomy* conceptualizes whether the purposes of a multimedia object match the teacher's core target purposes for the task (RA++), match their target purposes for the lesson (RA+), come from beyond the lesson (RA–) or come from beyond the unit (RA– –).

More succinctly, *positional autonomy* will show relations between the content expressed by a multimedia object and that required by a teacher's task, and *relational autonomy* will show relations between the purposes for which that content is used in a multimedia object and the purposes needed by a teacher's task.

We shall illustrate the usefulness of these concepts through analyses of two teachers using video animations in science classrooms.[6] Both examples are from Year 7 of secondary schooling in New South Wales, Australia. Both are from a unit of study called 'Earth and space sciences'. We develop specific translation devices for each analysis, showing contents and purposes for each task. Given that multimedia objects are complex sets of diverse elements, we analyze their key elements separately. We map these elements on an *autonomy plane*, as shown in Figure 4.1, divided into the 16 modalities generated by combining the strengths of positional autonomy and relational autonomy outlined above. By locating elements of each animation in relation to the teacher's targets, we show its epistemic affordances for the task, the pedagogic work required by the teacher to integrate the animation into the task, and whether the teacher succeeds.[7] By 'pedagogic work' we mean here changing the positions of elements on the plane. This can involve: *integration* or connecting to content (strengthening PA, or moving up on Figure 4.1); *disintegration* or disconnecting from content (weakening PA or moving down); *introjection* or turning to purpose (strengthening RA or moving right); and *projection* or turning to another purpose (weakening RA or moving left). We can also describe *addition*, where new contents or purposes are added, *subtraction*, where they are removed, and *substitution*. Through such changes, teachers and students can more closely match the knowledge practices of multimedia and tasks.

As we shall show, both teachers select animations whose interactive affordances match the interactional needs of their tasks and whose epistemic affordances largely

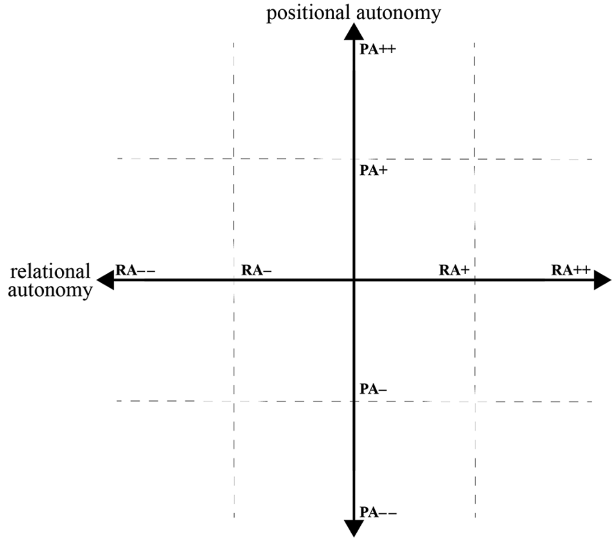

FIGURE 4.1 The autonomy plane (divided into 16 modalities)

match the knowledge practices they intend to teach. They are well suited but, as is typical for classroom practice, not perfect. In our first example, the animation's epistemic affordances need pedagogic work to activate their potential to support the task but the teacher does not provide that integrative pedagogy. In the second example, the teacher's pedagogic work makes the animation a closer match to the knowledge needs of her task by substituting the animation's audio elements with her own commentary. Both animations have limited interactive affordances but plentiful epistemic affordances, highlighting that these are not confined to interactions and require activating. The analyses thereby bring knowledge and teaching to the fore when examining integration.

Failing to activate epistemic affordances

The teacher's targets: Shooting for the Moon

In our example of teaching that fails to activate epistemic affordances, the teacher declares his target for the lesson at its outset: 'today we are going to continue on with the Moon'. For the task in question, the content of his core target concerns the Moon's rotation and its purpose is for students to answer two questions:

> I'm going to pose a question for you … [reading PowerPoint slide] 'Rotation of the Moon'. So write that down: 'Rotation of the Moon' … That's our topic. And then I want you to answer: does the Moon rotate on its axis?. If so, how fast does it rotate?

TABLE 4.3 Specific translation device for Moon animation task

target	The Moon in this lessson	++	***core***	Explanation in task, involving: Moon's orbit, length of orbit, rotation, length of rotation, synchronous rotation, facing side and 'dark side'
		+	***ancillary***	Other science knowledge concerning the Moon expressed in lesson (e.g. phases and eclipses)
non-target	Other knowledge	–	***associated***	Other science knowledge related to the Moon not included in lesson (e.g. tides) or topics in other lessons of the unit (e.g. seasons)
		– –	***unassociated***	Knowledge from beyond the unit

As summarized in Table 4.3, the teacher's *core target* concerns 'synchronous rotation'; in other words, that the time the Moon takes to rotate on its axis is almost the same as the time it takes to orbit the Earth, so we always see the same side. The rest of the lesson focuses on phases of the Moon and eclipses – these form the teacher's *ancillary target*. Other science knowledge related to his target, such as the Moon's role in tides, and from other topics in the same unit, such as seasons, form his *associated non-target*. Knowledge from beyond the unit is *unassociated non-target*.

The Moon animation

The task has two parts: discussion of a collage of static photographs and a video animation of 2:15 minutes length called 'Synchronous rotation'.[8] The animation comprises captions and two-dimensional images of entities, of which one (the Moon) moves. There is no sound. The animation has two main parts: simulations of different rotations of the Moon while orbiting the Earth; and a simulation of the changing shadow on the Moon created by sunlight during its orbit.

In the first main part a half-red and half-white Moon travels around an ellipse four times under the same top caption: 'Do we always see one side of the Moon?'. As shown by Figure 4.2, the first orbit is sub-captioned 'Moon without any rotation…' and the division between its red and white halves remains vertical during its orbit. After the orbit, the sub-caption is extended by: 'we see all sides in this case'. The second orbit is sub-captioned 'Moon with rotation' and the Moon rotates very quickly. As shown in Figure 4.3, after this orbit the words 'How fast is it rotating?' appear and a sub-caption states: 'This **isn't** actually what the Moon does…'. The third orbit is also sub-captioned 'Moon with rotation…' and the Moon spins so that its red side is always facing Earth. Central captions then appear: 'How fast is it rotating? It rotates on its axis **once** in the **SAME** time it takes to orbit us once!'.

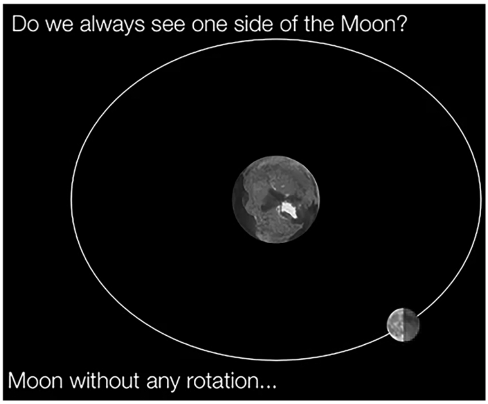

FIGURE 4.2 Moon animation: First orbit, without rotation (at 14 seconds)

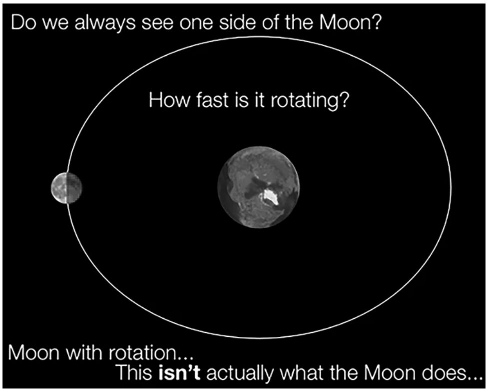

FIGURE 4.3 Moon animation: Second orbit, overly fast rotation (at 53 seconds)

To 'Moon with rotation…' is added 'we only see the red coloured side!!'. The Moon then repeats that orbit.

In the second main part, illustrated by Figure 4.4, the Sun is represented on the left. The top caption changes to 'Now again with the Sun's shadow' and a central caption states 'THE ROTATION PERIOD OF THE MOON IS EXACTLY THE SAME AS ITS PERIOD OF REVOLUTION!'. As it orbits, the right-hand side of the Moon remains darker. Another central caption appears: 'SYNCHRONOUS ROTATION! WILL EVENTUALLY HAPPEN TO THE EARTH TOO! (IT'S [sic] ROTATION RATE WILL SLOW DOWN TO EVENTUALLY MATCH ITS REVOLUTION RATE AROUND THE SUN)'. Finally, a sub-caption states: 'We always see the red coloured side! Position of the Sun's shadow does not move'.

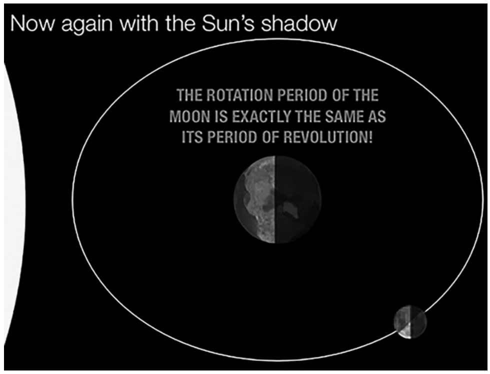

FIGURE 4.4 Moon animation: Sun's shadow simulation (at 1:53 minutes)

Affordances for the task

In terms of interactive affordances, the animation is relatively limited. It is freely accessible online, shareable, watchable, viewable (though not listenable), and can be played back. The animation is not easily manipulated, beyond pausing, repeating or jumping ahead. It does not lend itself to being redrawn or support actions such as drawing, writing or recording. These interactive affordances are associated by Bower (2017) with 'static/instructive' rather than 'collaborative/productive' interactions. Though limited in interactivity, the animation can support the teacher's stated purpose: students answering two questions about the topic.[9]

Epistemic affordances

To examine its epistemic affordances, Figure 4.5 presents the animation's elements on the autonomy plane, using the translation device of Table 4.3. (Positions *within* each modality do not denote differences in strengths). To give an indication of prominence, the shading offers a heuristic heat map of relative duration overall, from almost ever-present (darkest) through prolonged and briefer to momentary (lightest).[10]

As Figure 4.5 summarizes, the animation visually represents the teacher's core target knowledge: key factors – such as lengths of orbit and rotation – are animated at length to explain synchronous rotation (PA++, RA++). However, the animation also spends prolonged periods outside the teacher's target. The first minute comprises orbits with no rotation and with overly fast rotation, both of which are inaccurate. In terms of content, they are not part of the explanation (PA–). Whether they serve the purpose of learning about synchronous rotation depends on how this inaccuracy is presented. For the first orbit with no rotation, its inaccuracy is not made explicit. The caption asks whether we always see one side of the Moon, rather than stating that as a fact, and there is no indication that the viewer should judge whether, given that fact, the animated rotation is correct or not. Indeed, the caption implies the opposite: that the viewer should use the animated rotation to answer the question of whether we only see one side of the Moon. This orbit is thus not

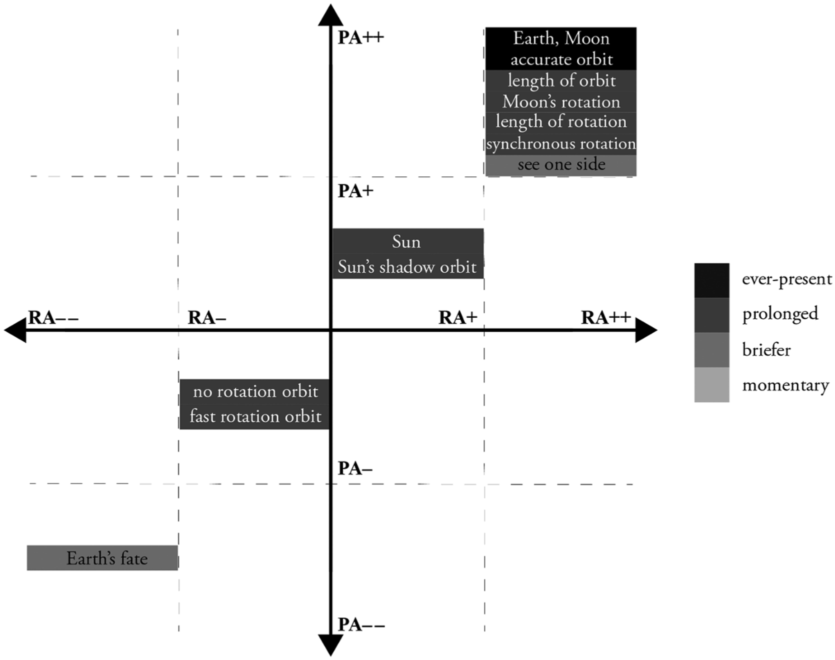

FIGURE 4.5 Autonomy analysis (with heuristic heat map) of Moon animation

serving the purpose of teaching synchronous rotation; it exhibits both non-target content and non-target purpose (PA–, RA–). The second orbit, with overly fast rotation, exhibits the same non-target content and purpose (PA–, RA–): only after the orbit ends and a caption asks how fast it is rotating does the animation make its inaccuracy explicit.

The third orbit represents the Moon's rotation accurately. Captions then ask and answer the teacher's second question of 'how fast' the Moon rotates: core target knowledge (PA++, RA++). During the final simulation showing the shadow on the Moon created by the Sun, this knowledge is further underlined by captions. The changing shadow itself is part of the teacher's wider target for the lesson: phases of the Moon (which the shadow demonstrates) is the next topic he discusses – ancillary target knowledge (PA+, RA+). Further from his target lies the caption about the Earth's fate, which is not part of the unit (PA– –, RA– –).

In summary, the animation's interactive affordances can support the teacher's 'instructive' task of having students consider two questions. The animation also exhibits significant epistemic affordances for the task. On both counts, then, it appears well selected. However, integration is more than selection. Our autonomy analysis shows that activation of its epistemic affordances requires pedagogic work by the teacher, specifically through *additions*. First, he needs to establish a shared understanding that the same side of the Moon is always seen from Earth and to clarify that the question is whether, given that fact, the rotation being simulated is accurate or not.[11] These additions would support the *introjection* or turning to purpose of the first two (inaccurate) orbits, strengthening their relational autonomy (and so moving them right on the plane to become PA–, RA++). Second, he could explicitly relate the simulation of the Sun's shadow (PA+, RA+) to his next task of discussing phases of the Moon. This addition would support both the *introjection* (turning to purpose, moving right) and the *integration* (connecting to content, moving up) of these elements into his core target (PA++, RA++). Doing so would expand his task to include setting up his subsequent discussion of Moon phases, making the task less discrete and the lesson overall more cumulative.

The dark side of the Moon

The teacher does not undertake the pedagogic work needed to activate the animation's epistemic affordances. He begins by asking students to answer his two questions by looking at a collage of pictures of the Moon from Earth:

> So, there are some pictures taken from all around the world, different days, alright? See if you can work out whether or not the Moon spins on its axis or not, and if it does, how fast it spins. So talk to the person next to you.

A student asks whether 'fast' means 'How many kilometres an hour?', but is not answered. Another student asks 'How are we supposed to know how fast it rotates if we've only got pictures?', to which the teacher's responds 'Well, if you think it turns once every night….'. Several minutes later, he tells the whole class:

> I'll give you a clue: the pictures, if you look very closely, and I've chosen these because they all show it, you just have to look very closely, it will answer the first part of the question for you. But you have to be careful and I'll explain why.

When he asks students to report back, several respond by stating that the Moon does spin. The teacher claims that a 'dot' appears on the Moon in every picture (though cannot point to it on several) and says this 'dot' shows that it spins. Thus what could establish that we always see the same side of the Moon – that pictures 'taken from all around the world, different days' have the same 'dot' – is instead used to state that the Moon rotates. On 'how fast' it spins, a student answers: 'Is it the same speed as the spin on its orbit? … It turns the same as the speed … like the speed of when the Moon turns, it's the same as the speed… the Moon rotating'. The teacher responds:

> Yeah, alright. Did everybody understand? … Now, let's watch a video to explain why it spins on its axis once every twenty-nine and a half days.[12]

So, the teacher has not added to the animation that: the same side of the Moon is always seen from Earth; this fact should be used by students to judge whether the animation's simulations are accurate; and several simulations will be inaccurate. Instead he plays the first (inaccurate) orbit and says: 'Now, it's just a visual with some … but you actually have to watch it, okay? There's no sound, just watching'. After the first orbit he pauses the video and says 'Alright, so that's what happens. We'll play that again. Alright? We'll play that again'. He thus presents the inaccurate orbit as accurate.

The teacher returns to the start and states that the red 'side' of the Moon is 'the dark side' and 'the side that you actually see'. He asks 'what happens if it doesn't spin?' and plays the first orbit again. These additions still do not establish that only one side is visible from Earth and that simulations may be inaccurate. The students remain unusually silent and the teacher answers his own question: 'we can see the opposite side of the Moon… but we don't ever see the opposite side of the Moon, so that can't work'. To this a student loudly exclaims 'What?!'. The teacher then plays the second orbit (fast rotation) while saying 'Now, so again you'd see all sides of the Moon, so that's not the case'. A student responds hesitantly: 'I don't think… does the Moon spin like that?'. As the third (correct) orbit plays, a student adds 'It seems the red side is always facing us', to which the teacher confirms 'The red side *is* always facing the Earth … So yeah, it takes – every time it orbits the Earth, it spins once on its axis'. Whether by 'red side' he means in the animation or reality is not clear. After the teacher says this is what the student was saying in his answer prior to the animation, another student loudly exclaims: 'There's only one person understanding! There's only one person understanding!'.

The teacher pauses the animation and tells students to write down a caption as their answer: 'It rotates on its axis **once** in the **SAME** time it takes to orbit us once!'. After two minutes he continues the animation, reading out a caption that calls the phenomenon 'synchronous rotation'. The teacher ignores the Sun's shadow simulation and eschews the opportunity to connect the animation with phases of the Moon. He then opens a new PowerPoint slide and begins discussing that topic separately.

In summary, the animation offers much that is needed for the teacher's task. He activates some of the animation's limited affordances for interactivity, principally pausing and replaying. However, while doing so he deactivates the animation's epistemic affordances. Instead of adding knowledge that could turn to purpose the simulations of its first part, introjecting 'no rotation orbit' and 'fast rotation orbit' rightwards on Figure 4.5 (to become PA–, RA++), he suggests the first orbit is correct and within his core target, replaying the orbit as if it was accurate. What is and is not core target content is thus unclear. As illustrated by the outbursts of students expressing confusion, it is likely many remained in the dark about the Moon's synchronous rotation. Second, he does not add to the second part (on the Sun's shadow) anything to activate its affordance for connecting to his next topic. Thus the task remains segmented from other knowledge he discusses in the same lesson.

Activating epistemic affordances through pedagogic work

The teacher's targets: The seasons

To illustrate how a multimedia animation can be successfully integrated into teaching a scientific explanation, we turn to a different teacher at a different school but teaching the same unit ('Earth and space sciences') in the same curriculum (New South Wales) at the same level (Year 7 secondary school). The teacher makes her target for the lesson explicit at the outset:

> The last time I saw you, we were talking about day and night, we were talking about the tilt of the Earth on its axis, and we had started to discuss seasons. That's what we're going to be looking at today.

As she tells students, the core target content for the task is how 'the tilt of our axes and our position around the Sun' shape Earth's seasons and her core target purpose is to support their understanding of that explanation:

> If you'd like to make some notes of things that you might think are important, it's a good time. Later on, we're going to ask some questions to see how much you understand.

Scientific explanations can become extremely complex. Not all factors in an explanation may be taught in a particular syllabus, year of schooling, unit or task. 'The seasons' is one such explanation – not everything on the topic necessarily lies within this teacher's targets. A 'constellation analysis' of this lesson by Maton and Doran (chapter 3, this volume) shows the factors involved in this specific task to be: Earth's axis is tilted, Earth has hemispheres, Earth orbits the Sun, that bringing those three together means the hemispheres point towards or away from the Sun through the year, the Earth receives energy from sunlight, that pointing towards or away the Sun means the angle of that sunlight varies, and that this creates the variations in temperature through the year known as 'seasons'. As summarized in Table 4.4, this summarizes the teacher's *core target,* both its content (those factors and relations) and purpose (teaching those factors and relations) – it shows what she means by 'the tilt of our axes and our position around the Sun'.

Maton and Doran (Chapter 3) also show that the teacher discusses other factors in different explanations of the seasons she gives during the rest of the lesson, specifically: that the Earth rotates, that pointing towards or away from the Sun while the Earth rotates leads to variations in the length of daylight, and that changes in daylight length helps explain the seasons. These factors form her *ancillary target* (see Table 4.4). Her *associated non-target* comprises other topics in the unit, such as the Moon, or further factors explaining the seasons not discussed in the lesson, such as how variations in sunlight angle create variations in the concentration of sunlight in each hemisphere.[13] Finally, *unassociated non-target* knowledge is anything else outside her target.

TABLE 4.4 Specific translation device for seasons animation task

target	Explanations of the seasons in this lesson	++	***core***	Explanation in task, involving: Earth's tilt, hemispheres, orbit, hemispheres point towards or away from Sun, solar energy, variations in angle of sunlight, variations in temperature called 'seasons'
		+	***ancillary***	Factors for seasons in other explanations in lesson (e.g. Earth rotation and length of daylight).
non-target	Other knowledge	–	***associated***	Other science knowledge related to seasons not covered in lesson (e.g. sunlight concentration) or topics in other lessons of the unit (e.g. the Moon)
		– –	***unassociated***	Knowledge from beyond the unit (e.g. door shutting sound effect)

The seasons animation

The multimedia object is a two-minute long animation called 'What causes Earth's seasons?' that includes entities, movements, visual effects, captions, labels, spoken narration (a female human voice with American accent), music and sound effects.[14] The animation can be distinguished into four main explanatory stages: (i) focusing the question of what causes Earth's seasons on the role of axial tilt; (ii) outlining an explanation; (iii) showing how this leads to seasons changing through the year; and (iv) summing up.

The animation begins by asking as voice and title text: 'What causes Earth's seasons?'. Electronic, 'jazzy' music continues throughout the animation. Patterned panels leave the title screen to the sound of a heavy door shutting. A photorealistic Earth rotates (to whirring sounds) and becomes abstracted, as illustrated by Figure 4.6, to display continents, latitude and longitude lines, and an axis line. At the same time the voice answers itself: 'Earth's seasons are caused by Earth's tilt on its axis. Instead of going straight up and down [a green vertical line appears briefly through the Earth], Earth's axis tilts 23.5 degrees'. Then the Earth orbits the Sun (while orbited by the Moon), as the voice asks: 'Can you see why the tilt causes Earth to have seasons throughout the year? Let's find out!'.

Second, over a static, rotating Earth, as illustrated in Figure 4.7, the narration outlines how tilt affects the angle of sunlight:

> Here's the energy of the Sun [rumbling sound as yellow band extends from Sun to Earth]. Notice that it hits the lower half of Earth [cymbals sound as equator glows; lower half turns yellow], called the southern hemisphere, most directly

FIGURE 4.6 Seasons animation: Showing Earth's tilt (at 18 seconds)

> [hemispheres labels appear]. The Sun's energy hits the northern hemisphere too [sunlight hitting top half turns blue], but look at how the northern hemisphere is pointed away from the Sun [arrow upwards through Earth's axis]. Also, the light hits at an angle [two arrows appear in sunlight band] that causes the energy to be spread out over a greater area. So, at this spot in Earth's revolution it receives less of the Sun's energy.

The narration then describes the effects of different sunlight concentration on hemispheres:

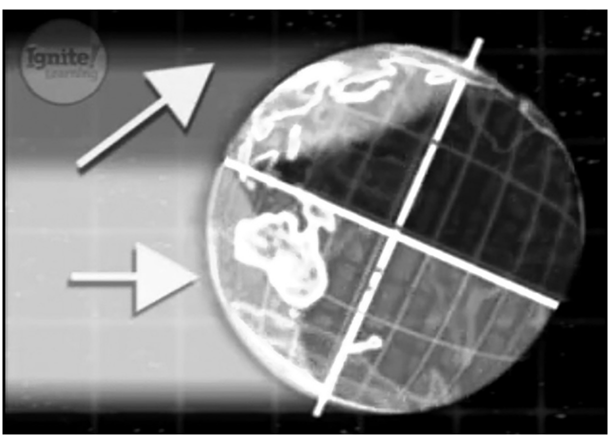

FIGURE 4.7 Seasons animation: Different angles of sunlight hitting the Earth (at 51 seconds)

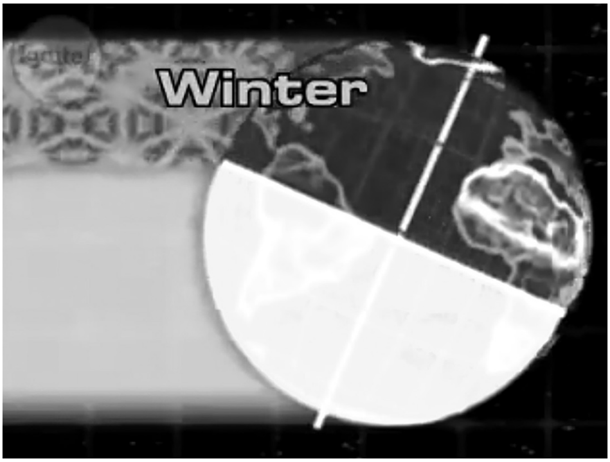

FIGURE 4.8 Seasons animation: Effects of angle and concentration of sunlight – winter (at 1:23 minutes)

> When more of the Sun's energy hits the southern hemisphere it causes the temperature to go up [sun patterns and 'Summer' appear in yellow band]. It's summertime! [Sounds of children playing] More sunlight, longer days! With less of the Sun's energy hitting the northern hemisphere, it gets a lot colder [snowflake patterns and 'Winter' appear in blue band; see Figure 4.8]. Put on your winter coat! [Sounds of wind howling] Less sunlight, shorter days!

Third, the animation shows the seasons through the year: 'Let's see how the seasons change as Earth revolves around the Sun'. The caption 'December' appears (to door sound) and the animation proceeds through months of the year (signalled by a keyboard tap sound) as the Earth orbits the Sun. At 'March' the Earth is labelled with 'Spring' with green patterns on the top half and 'Autumn' and brown patterns on the bottom half; at 'June', as illustrated by Figure 4.9, 'Summer' and 'Winter' with yellow and blue patterns; and at 'September', 'Autumn' and 'Spring' with brown and green patterns. Month captions move around the screen, with the door sound when they stop.

Finally, the voice sums up: 'So why do seasons change? Because the tilt of Earth's axis causes the hemispheres to receive different amounts of the Sun's energy'. The Earth orbits the Sun as month captions are tapped through again. The door sound marks the appearance of a photograph of a green hillside next to text stating 'Seasons occur because of Earth's tilt!', as the voice says breathily: 'That's some *cool* science!'.

Affordances for the task

The animation offers limited interactive affordances. It is accessible, shareable, watchable, viewable, listenable, and can be played back. One can choose to only listen or only watch, but the animation is not easily manipulated; for example,

FIGURE 4.9 Seasons animation: Summer/Winter (at 1:41 minutes)

the voice cannot be altered, specific audio elements (such as the music) cannot be turned off and specific content (such as discussion of particular factors) cannot easily be removed. Nonetheless, these affordances for 'instructive' interactions can meet the teacher's purpose of students making notes of key issues explaining the seasons.

Epistemic affordances

The animation's complex mix of elements exhibit different degrees of match to the task. So we shall discuss visual and audio elements in turn, using the translation device of Table 4.4.

Visual elements include text (title, labels, captions), entities (e.g. Earth), movement (e.g. rotating), a photograph and various effects (e.g. yellow band for sunlight). Figure 4.10 locates these elements on the autonomy plane: most are at the far top (PA++) and/or far right (RA++). Overall, the animation thereby visually matches the teacher's core target content and/or purpose. Taking each kind of visual element in turn, text appears frequently, though each briefly. All text – summarized in Figure 4.10 for reasons of space as 'all captions', 'all labels' and 'titles' – is situated in the teacher's core target (PA++, RA++). Entities and movements, such as Earth and its orbit, are also largely in her core target. The exceptions are: Earth's rotation and the Moon and its orbit. Both, however, were previously discussed in the class: Earth's rotation was a factor in an explanation discussed earlier in the lesson (PA+, RA+); and the Moon and its orbit was discussed in the previous lesson (PA–, RA–). Other visual elements are in the teacher's core target: axis line, sunlight band and sunlight arrows are part of the explanation and students' ability to use these symbols in diagrams is checked by the teacher later in the lesson. Other visual effects are mostly brief and located at the bottom right of Figure 4.10. While their contents – colours, patterns, glowing – are far from the seasons (and so coded as unassociated non-target content or PA– –), they all serve the teacher's core target purpose (RA++) by

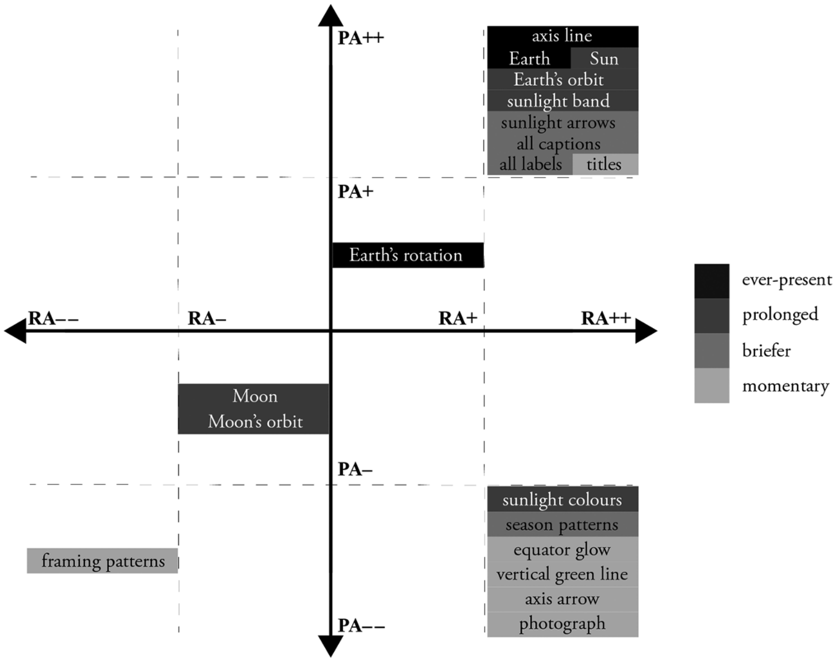

FIGURE 4.10 Visual elements of the seasons animation

emphasizing factors such as different hemispheres and seasons. The one exception is only momentary: patterns framing the static images at the start and end (PA– –, RA– –).

Audio elements include a spoken narration, voice tone, music and various sound effects (e.g. howling wind). The almost ever-present narration, shown as non-italics in Figure 4.11, covers all factors and relations that comprise the explanation of seasons in the teacher's core target (PA++, RA++).[15] It would thus appear ideally suited to the task. However, the narration also includes two further factors: daylight length is discussed in another explanation during the lesson but not in this task (PA+, RA+); and concentration of sunlight, though related to the seasons, is not addressed in the lesson (PA–, RA–). The narration also exudes an excitable, breathy tone, especially in playful phrases (e.g. 'Put on your winter coat!') – these are located at the bottom left of the plane, far from the teacher's core target (PA– –, RA– –). Other audio effects (*italics* in Figure 4.11) are frequent but individually brief. Sounds of rumbling, children playing, etc. represent non-target content (PA– –) but serve the teacher's core target purpose (RA++) by emphasizing factors such as solar energy and seasons. Exceptions are: whirring for Earth's rotation (PA– –, RA+); and the recurrent door shutting sound and ever-present background music (PA– –, RA– –).

In summary, the animation's interactive affordances can support the teacher's 'instructive' task of students making notes of key issues. The animation also exhibits

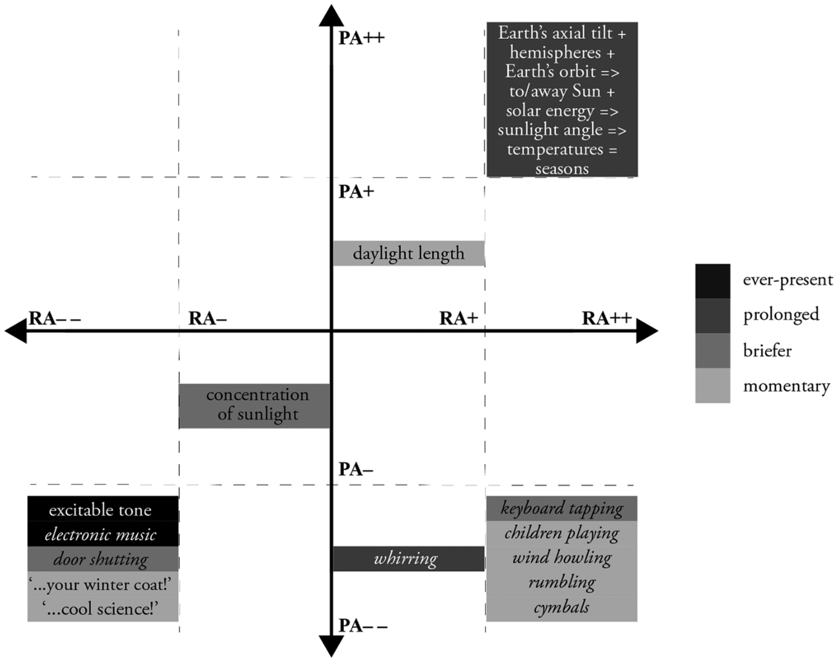

FIGURE 4.11 Audio elements of the seasons animation

significant epistemic affordances for the task. Visually, what does not lie within the teacher's core target is either part of the lesson and unit of study or only a momentary feature of the animation. Aurally, the spoken narration includes all the factors and relations that the teacher wishes to convey. In short, the animation is well selected for both interactive and epistemic affordances. However, as we emphasize, multimedia objects are unlikely to perfectly match a specific task in a specific classroom. In this case, two issues could potentially require pedagogic work. First, factors in the narration that the teacher does not wish to include (daylight length and concentration of sunlight) are not easily subtracted. Second, the ever-present voice tone and music, if not wanted, can only be subtracted by omitting all audio elements. Given that the visual elements do not by themselves provide an explanation, this requires adding a commentary. The success of such *substitution* – replacing non-target with core target elements – would depend on the teacher's ability to discuss core target knowledge while selecting and turning to purpose the animation's visual elements.

Seasons in the Sun

The teacher undertakes the pedagogic work required to maximize the animation's epistemic affordances for supporting her task. She does so by taking advantage of its watchability and listenability, muting the animation and substituting the audio with her own narration over the visual elements. In an interview, she highlighted its terminology, music and voice tone as reasons – epistemic rather than interactive affordances:

> I didn't use the sound in that one because I wanted to be able to use the language that I was using in class, that the sound in that animation was a very hard American voice, almost computerised. There was this tinkly music in the background. I thought, 'This is going to be distracting'.

As we state above, such substitution depends on a teacher's ability to add audio content while activating an animation's visual elements. In this case, the teacher is highly adept. Without pausing the animation, she highlights, through her speech or gestures, specific entities, movements, visual effects and text while introducing factors and explaining how they relate together to create the seasons. The teacher also asks questions of students that are timed so that the appearance of captions confirms their responses. In short, the animation and teacher narration form an integrated multimedia and multimodal performance.

To show the pedagogic work this involves, we shall discuss the task using the same four stages as the animation's voiceover (above). As outlined earlier, her core target is to explain how 'the tilt of our axes and our position around the Sun' shape Earth's seasons. First, she highlights the key issue of tilt:

> So [reading out title] what causes Earth's seasons? When we have a little look at this animation, what we're looking at here is obviously the Earth spinning on its axis and you can see that that axis [hand gesture matching its axis line] is about 23.5 degrees [points to axis line] from [hand traces vertical line] what could be the [air quotes gesture] "theoretical midline" of the Earth. We know [repeatedly points to Earth as it orbits Sun] that that axis holds itself. Can you see [pointing to Earth] how it's holding its 23.5 degrees as it moves around the Sun?

Figure 4.12 plots key elements of her narration as a whole.[16] As the above shows, she begins by quickly turns from describing what is being shown (Earth rotates) to the issue of axial tilt, selecting visual elements relevant to her core target: Earth's axis, tilt and orbit (PA++, RA++). The teacher's regular gestures are non-target content (PA– –), because hand movements are far from her target content, but they serve her core target purpose (RA++) by, for example, highlighting tilt.

Second, the teacher set out an explanation of how tilt leads to differences in the angle of sunlight in different hemispheres:

> Now, [pointing to yellow band from Sun] when the Sun's rays hit the Earth, the Earth has that also other [air quotes] "theoretical midline", the equator [hand traces equator line], that breaks it into half: [pointing to labels] northern hemisphere and southern hemisphere. Okay? We're [pointing to herself] in the

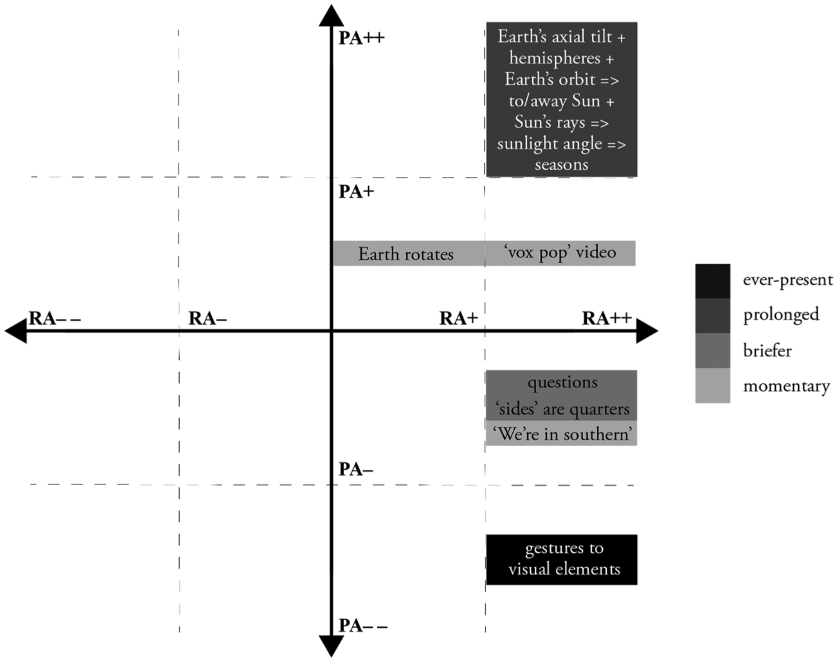

FIGURE 4.12 Teacher narration of the seasons animation

> southern hemisphere and at some times [tracing horizontal line in yellow band] the sunlight will strike, in this case, the southern hemisphere at that 90 degree angle. All right? And here [hand tracing angled arrow in sunlight band], this is what we can sometimes call an 'oblique'. You heard that person in the vox pop talk about it. Yeah? Or 'glancing'. So [hand tracing where angled arrow had been] these are like the 15 degrees, okay? We're getting sunlight bouncing off, and here [hand tracing where horizontal arrow had been] it's hitting directly.

Through this explanation the teacher's gestures continue linking visual elements to her core target knowledge: the sunlight band is recruited into discussing the Sun's rays, the equator line helps identify hemispheres, and the arrows are mirrored by gestures that indicate sunlight angles. In comparison to the muted narration, she offers a simpler explanation by not discussing the effects of sunlight angle on daylight length or on sunlight concentration and their effects, in turn, on temperatures. Instead, these elements are substituted by: locating herself and her students in the southern hemisphere; providing more information about sunlight angles, specifically the terms 'oblique' and 'glancing'; and explicitly connecting that information to a 'vox pop' video they watched earlier in the lesson. Everything she adds serves her core target purpose (far right on the Figure, or RA++) and helps integrate the task and animation into the rest of the lesson and thus the classroom experiences shared by students.

Third, the teacher checks student understanding of the effects of sunlight angle on seasons and, emphasizing the Earth's tilt during its orbit of the Sun, discusses how seasons change through the year:

> So, in this case, what season does the southern hemisphere have? [Students say 'summer', as label appears]. And what about the northern hemisphere? [Students say 'winter']. Winter! Good. Now, when this moves [gesturing to Earth] around the Sun, and holds its axis, because it doesn't … the axis won't change around like that, when this moves to the other side of the Sun, we will see the other side of the Earth … so [pointing to screen showing Earth with 'spring' and 'autumn' labels] now we're on the back side of the Sun. We've got spring and autumn. Now we're on the opposite side [Earth with 'summer' and 'winter' labels]. Now the northern hemisphere has summer and the southern hemisphere has winter. Now, we come out to the [air quotes] "fourth side" of the Sun [Earth with 'autumn' and 'spring' labels], we get autumn and spring split around.

Here the questions to students are not part of the explanation (PA–) but turned to her core target purpose (RA++), as shown on Figure 4.12. She then recruits visual entities (the Earth and the Sun), movements (Earth orbiting) and labels (e.g. 'winter') to discuss the changing seasons, remaining throughout inside her core target.

Finally, the animation continues as a student queries the description of 'sides' and the teacher explains that 'sides' is a way of emphasizing the change of seasons by referring to quarters of Earth's orbit: non-target content turned to her core target purpose (PA–, RA++). The animation's final textual summary is not referred to by the teacher. Instead, after it concludes she sums up: 'So, we know the Sun is hitting the Earth. We know that some parts of the Earth will be getting the full force and some will be getting those glancing rays.' She asks the students whether the Sun changes and emphasizes: 'typically the strength of the Sun never changes. The thing that will change is our position in relationship to the Sun … We get seasons because of being tilted towards or away'. This concludes the task; the teacher then moves to a task involving an animated simulation that shows the seasons change through the year.

In summary, the teacher uses the animation's ability to be watched and muted in order to reshape its epistemic affordances. Her substitution of audio elements with her own narration and gestures adds elements that are almost entirely on the far right of Figure 4.12 – everything she says or does is turned to her core target purpose. Indeed, Figure 4.12 underplays the extent to which her performance as a whole, and not just her audio narration, is replete with core target knowledge because, for reasons of space, we summarized 'gestures to visual elements' rather than included all those elements she activates in this way. Returning to the plane of visual elements in Figure 4.10, she draws extensively on entities, movements and labels located within her core target: axis line, Earth, Sun, orbit, sunlight band, arrows, titles, captions and labels. In contrast, she ignores those visual elements outside her target. Those which could have served her purpose – the visual effects at the bottom right of Figure 4.10 – were substituted by hand gestures bringing attention to key factors. So, the teacher selects the animation's visual elements that match her task and integrates those elements through gesture with an audio narration that provides a simpler, more focused explanation that is, in addition, more integrated into the wider lesson and classroom experience. Her strategy of substitution thereby not only activates the epistemic affordances of the animation but more closely integrates the multimedia object into the task and lesson.

Conclusion

Multimedia objects such as animations are a common part of teaching science. Questions of how teachers can integrate such ready-made objects into classroom tasks are urgent. However, such questions are sidelined by the cognitive–learning–design axis dominating research into multimedia learning and technology affordances. To address questions of integration requires studies of actual classroom practice and a framework that does not reduce teaching to designing and what is being taught and learned to homogeneous information. In this chapter we extended the metaphor of 'affordances' beyond its current focus on enabling students interactions to embrace the *epistemic affordances* of knowledge practices. We drew on the LCT dimension of Autonomy to bring one aspect of these knowledge practices into view. The concepts of *positional autonomy* and *relational autonomy* helped foreground relations between the contents and purposes of multimedia and those of classroom tasks. The concept of *targets* helped ensure that specific classroom practices remained the centre of analysis, thereby avoiding the slide into generic descriptions of context-free 'abilities' towards which affordance frameworks tend. These concepts provided a platform for seeing that teaching is more than design, that integration is more than selection, and that affordances are more than enabling interactive practices among students.

We illustrated the value of seeing epistemic affordances with two examples of teaching science with animations. Both teachers selected animations whose limited interactive affordances matched their 'instructive' needs – from the conventional perspective of 'affordances' there is little to distinguish between them. Yet they offer contrasting examples of teaching science with multimedia. The first teacher did not undertake the pedagogic work required to activate the epistemic affordances of the Moon animation for supporting his task (teaching about synchronous rotation) and left that task segmented from the rest of the lesson. The second teacher undertook pedagogic work by substituting the audio elements in the seasons animation that did not match her specific task with her own narration and connecting this knowledge to its visual elements through gestures. From the viewpoint of epistemic affordances for teaching scientific explanations, then, these examples are radically different.

By bringing teaching and knowledge practices into view, autonomy analysis emphasizes that integration does not end with design or selection. While multimedia are unlikely to perfectly match the knowledge needs of a specific classroom task, that is not necessarily an obstacle to their integration. Elements beyond a teacher's core target offer possibilities for teaching and pedagogic work by teachers and students can 'connect to content' (strengthen PA) and 'turn to purpose' (strengthen RA) those elements of a resource that lie beyond their core targets. Thus, ready-made multimedia objects can be integrated through classroom practice. Moreover, the epistemic affordances of a multimedia object may differ wildly from one task to the next. The coding of an object is in relation to targets that are highly specific: a particular task in a particular lesson. The same multimedia objects analyzed in relation to other teacher's targets, to other tasks of these teachers or to students' targets will result in different codings. Epistemic affordances depend on the specific knowledge practices being taught and learned. Thus, design and selection are not the end of the matter: integration is a practice by teachers and students in classrooms.

Of course, seeing teaching, knowledge practices and epistemic affordances is but a small step forward. One cannot expect teachers to undertake time-consuming autonomy analyses of tasks and multimedia. The next step requires more practice-oriented outcomes. Autonomy analyses of classroom practices that integrate mathematics into science (Maton and Howard, chapter 2, this volume) and everyday experiences into History teaching (Maton and Howard 2018) have developed the pedagogic practice of 'autonomy tours', which is already having an impact on teaching practice. Similar pedagogic principles are required for integrating multimedia into teaching. Nonetheless, this chapter has illustrated that LCT offers the potential for addressing such issues of integration. All we have to do now is to activate those affordances.

Notes

1 This holds for models of both 'technological' affordances and also 'social' and 'educational' affordances (Kirschner *et al.* 2004) – all concern interactions.
2 We use 'epistemic affordances' to encompass all knowledge practices, whether involving epistemological constellations of concepts and empirical descriptions or axiological constellations of affective, moral, ethical or political meanings (Maton 2014: 148–70).
3 See: www.legitimationcodetheory.com.
4 There is a growing body of work using Semantics to study multimedia in science, such as student-generated digital products (Georgiou 2020, Georgiou and Nielsen 2020). From a complementary perspective, He (2020) explores the semiotic resources of science animations with systemic functional linguistics.
5 Students, other teachers, etc. may have different targets, allowing comparative analysis of, for example, learning experiences.
6 We draw on research funded by the Australian Research Council (DP130100481), led by Karl Maton, J. R. Martin, Len Unsworth and Sarah K. Howard.
7 The concepts can be enacted in different ways. In Maton and Howard (2018, chapter 2, this volume), we focus on changes in knowledge practices over time and so plot 'autonomy pathways' between different 'autonomy codes' on the plane. Here we do not name autonomy codes, as our focus is on 16 rather than four modalities, and we plot a synchronic analysis of positions, as our focus is relating task and object rather than changes in strengths through time.

8 The animation is freely available on the Internet. The earliest we discovered was uploaded to YouTube in 2009 by 'astrogirlwest', about whom no further information is available.
9 For both animations analysed in this chapter, it is easy to imagine different resources that could make the tasks more collaborative for students. However, that would not diminish their ability to support 'instructive' interactions and thus match the teachers' core target purposes.
10 Relative duration is, of course, but one indicator of prominence – one could also examine relative size, position, and other attributes.
11 One uploader to YouTube added their own starting caption: 'This is a video explaining why we always see the same side of the moon all the time'; see https://www.youtube.com/watch?v=6vkVxu04DcE.
12 The teacher confuses the duration between New Moons (29.5 days) with the Moon completing a revolution on its axis (27.3 days). However, accuracy here would not change the degree to which he integrates the animation.
13 These factors are highlighted in a constellation analysis of secondary school science textbooks by Maton and Doran (chapter 3, this volume).
14 The animation is dated 2006, accredited to Ignite! Learning, and freely available at https://www.teachertube.com/videos/what-causes-seasons-on-earth-657.
15 We have included the logic of its explanation by using '+' and '=>' to refer to links between nodes; see Maton and Doran (chapter 3, this volume).
16 We have highlighted the logic of her explanation with '+' and '=>'. Maton and Doran (chapter 3, this volume) discuss this logic in greater detail.

References

Antonenko, P., Dawson, K. and Sahay, S. (2017) 'A framework for aligning needs, abilities and affordances to inform design and practice of educational technologies', *British Journal of Educational Technology*, 48(4): 916–27.

Berney, S., and Bétrancourt, M. (2016) 'Does animation enhance learning?: A meta-analysis', *Computers & Education*, 101: 150–67.

Bower, M. (2008) 'Affordance analysis – matching learning tasks with learning technologies', *Educational Media International*, 45(1): 3–15.

Bower, M. (2017) *Design of Technology-Enhanced Learning: Integrating Research and Practice,* Bingley: Emerald Publishing.

Georgiou, H. (2020) 'Characterising communication of scientific concepts in student-generated digital products', *Education Sciences*, 10(1): https://doi.org/10.3390/educsci10010018.

Georgiou, H. and Nielsen, W. (2020) 'New assessment forms in higher education: A study of student generated digital media products in the health sciences', in C. Winberg, S. McKenna and K. Wilmot (eds) *Building Knowledge in Higher Education*, London: Routledge, 55–75.

Hammond, M. (2010) 'What is an affordance and can it help us understand the use of ICT in education?', *Education and Information Technologies*, 15(3): 205–17.

He, Y. (2020) '*Animation as a Semiotic Mode: Construing Knowledge in Science Animated Videos*', unpublished PhD thesis, University of Sydney, Sydney.

Howard, S. K. and Maton, K. (2011) 'Theorising knowledge practices: A missing piece of the educational technology puzzle', *Research in Learning Technology*, 19(3): 191–206.

Howard, S. K. and Maton, K. (2013) '*Technology & knowledge*', *AERA 2013 SIG-Computer and Internet Applications in Education*, San Francisco, USA: AERA, 1–8.

Jenkinson, J. (2018) 'Molecular biology meets the learning sciences: Visualizations in education and outreach', *Journal of Molecular Biology*, 430(21): 4013–27.

Kirschner, P., Strijbos, J.-W., Kreijns, K. and Beers, P. J. (2004) 'Designing electronic collaborative learning environments', *Educational Technology Research & Development*, 52(3): 47–66.

Li, J., Antonenko, P. D. and Wang, J. (2019) 'Trends and issues in multimedia learning research in 1996–2016: A bibliometric analysis', *Educational Research Review*, *28*; 100282

Maton, K. (2014) *Knowledge and Knowers: Towards a Realist Sociology of Education*, London: Routledge.

Maton, K. (2020) 'Semantic waves: Context, complexity and academic discourse', in J. R. Martin, K. Maton and Y. J. Doran (eds) *Accessing Academic Discourse,* London, Routledge, 59–85.

Maton, K. and Chen, R. T-H. (2016) 'LCT in qualitative research: Creating a translation device for studying constructivist pedagogy', in K. Maton, S. Hood and S. Shay (eds) *Knowledge-building: Educational studies in Legitimation Code Theory*, London: Routledge, 27–48.

Maton, K. and Howard, S. K. (2018) 'Taking autonomy tours: A key to integrative knowledge-building'*, LCT Centre Occasional Paper* 1: 1–35.

Mayer, R. E. (2003) 'The promise of multimedia learning: Using the same instructional design methods across different media', *Learning and Instruction*, 13(2): 125–39.

Mayer, R. E. (2014a) 'Cognitive theory of multimedia learning', in R. E. Mayer (Ed.) *The Cambridge Handbook of Multimedia Learning*, 2nd edition, Cambridge: Cambridge University Press, 43–71.

Mayer, R. E. (2014b) (Ed.) *The Cambridge Handbook of Multimedia Learning*, 2nd edition, Cambridge: Cambridge University Press.

Mayer, R. E. and Fiorella, L. (2014) 'Principles for reducing extraneous processing in multimedia learning', in R. E. Mayer (Ed.) *The Cambridge Handbook of Multimedia Learning*, 2nd edition, Cambridge: Cambridge University Press, 279–315.

Mayer R. E. and Moreno, R. (2003) 'Nine ways to reduce cognitive load in multimedia learning', *Educational Psychologist,* 38(1): 43–52.

Mutlu-Bayraktar, D., Cosgun, V. and Altan, T. (2019) 'Cognitive load in multimedia learning environments: A systematic review', *Computers & Education*, 141: 103618.

Ploetzner, R. and Lowe, R. (2012) 'A systematic characterisation of expository animations', *Computers in Human Behaviour*, 28: 781–94.

Sweller, J., van Merriënboer, J. and Paas, F. (2019) 'Cognitive architecture and instructional design: 20 years later', *Educational Psychology Review, 31*: 261–92.