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

LCTC

TEACHING SCIENCE

Knowledge, Language, Pedagogy

Legitimation Code Theory

ROUTLEDGE

3

CONSTELLATING SCIENCE

How relations among ideas help build knowledge

Karl Maton and Y. J. Doran

Comprising a simple explanation of a complex phenomenon,
namely complex explanations of seemingly simple phenomena.

Introduction

Science is complex. This is not simply a matter of the extraordinarily large number of ideas, practices and beliefs that comprise science; it also concerns the manifold ways in which they are related together. These complex relations pose challenges for teaching science. Even after isolating a topic and deciding the level of detail to teach, questions arise of where to begin and how to proceed through the diverse connections among ideas that constitute a scientific explanation. To address these questions requires an understanding of different kinds of relations among ideas. Yet, there remains a need for concepts that reveal and analyze those relations, thanks to knowledge-blindness and atomism.

'Knowledge-blindness' (Maton 2014) describes the way the forms taken by knowledge remain unseen by research. Most approaches instead explore either kinds of knowers or ways of knowing. Sociologically-inflected approaches emphasize that 'knowledge' reflects dominant interests and focus on *whose* knowledge is taught and learned (Ellery 2017), a concern with kinds of knowers that is increasingly salient in calls to 'decolonize' science (Adendorff and Blackie 2020). More common in science education are psychologically-inflected approaches that assume 'knowledge' comprises mental processes and so focus on 'conceptions' and ways of thinking (see Georgiou *et al.* 2014). For example, the notion of 'threshold concepts' appears to highlight relations among ideas: they are 'concepts that bind a subject together' (Land *et al.* 2005: 54). However, the nature of those relations is not analysed. A 'threshold concept' is defined as 'opening up a new and previously inaccessible way of thinking about something' (Meyer and Land 2003: 1). It is identified by being 'transformative', 'integrative', 'irreversible', and often 'troublesome' for students and distinguished from a 'core concept' that 'progresses understanding of the subject' without transforming students' ways of thinking (Meyer and Land 2003: 4). Leaving aside their ill-defined nature (Salwén 2019), these concepts focus entirely on ways of knowing. The forms taken by 'core' and 'threshold' concepts are not part of the picture. Taken together, that research is concerned with kinds of knowers or ways of knowing means that knowledge as an object of study in its own right, one that takes different forms, forms which have effects for all kinds of issues, is left out of the picture.

The second reason, atomism, describes how knowledges (and ways of knowing) are viewed atomistically, as if theories, explanations, etc. are simply collections of individual ideas. For example, diSessa (1993) defines 'phenomenological primitives' or 'p-prims' as knowledge in physics that students intuitively believe to be irreducible features of reality. As well as focusing on knowing, this notion illustrates atomism: how these ideas relate to other ideas to form an explanation remains unclear. As diSessa states, the approach views 'knowledge in pieces' (1993: 111). This is akin to listing ingredients but not describing the recipe, as if how ingredients are combined does not affect what is created. Such atomism also characterizes typologies – such as Shulman's 'PCK', 'TPCK', and Bloom's taxonomy – which list different kinds of 'knowledge' but do not conceptualize relations among those types.

Given these tendencies to knowledge-blindness and atomism, there remains a need for concepts to grasp different relations among ideas. This issue was helpfully opened up by systemic functional linguists exploring explanations in science (e.g. Rose *et al.* 1992, Unsworth 1997). Such work showed that ideas in explanations are connected in language through a range of relations of condition, cause and time. However, the issue of how relations among ideas affect how they are explained remains unclear. In this chapter, we draw on *constellations* from Legitimation Code Theory (Maton 2014) to conceptualize and visualize relations among ideas. We focus on analyzing explanations, a key genre in science education (Unsworth 1997). Our aim is to illustrate how constellation analysis can show the significance of relations among ideas for science teaching.

We begin by introducing the notion of *constellations*. We then make several simple conceptual distinctions relevant to our analyses in this chapter. These concepts are enacted in analyses of scientific explanations of tides and seasons, focusing on Year 7 of secondary school science in New South Wales, Australia. Analyzing textbooks created for this curriculum, we examine the logical relations among ideas in each explanation. Then, we examine how each explanation is taught by the same teacher in the same unit of study. From these analyses we argue that relations among ideas in the logic of explanations may affect how those explanations are taught in a school classroom. We conclude by considering how constellation analysis can provide educators with a pedagogic tool for making visible relations among the ideas they are teaching, and researchers with an analytic tool for making visible how knowledge changes when recontextualized between research, curriculum and classroom practice.

Constellations

A way of grasping relations among ideas is provided by *constellation analysis*, which forms part of *cosmological analysis* from Legitimation Code Theory (LCT). Cosmological analysis describes any set of stances (e.g. ideas, beliefs, practices, etc.) as a selection from a larger set of possible stances that has been arranged into a particular pattern or *constellation*, *condensed* with meanings, and *charged* with valuations, according to a particular *cosmology* or worldview (Maton 2014: 148–70).

Analogy from astronomy

As a way into the approach, consider the notion of 'constellations' in astronomy. On a clear night without light pollution one can see an enormous number of stars. As an example, the left image in Figure 3.1 shows some of the stars visible in a small part of the sky in the northern hemisphere. Of those stars, a small number have been selected and arranged into a pattern that is the *constellation* of 'Taurus' (middle in Figure 3.1). There may also be smaller *clusters*; for example, 'Pleiades' is a cluster of stars that lie within Taurus. As well as being constellated, the stars are *condensed* with meaning. For example, since the ancient Mesopotamians, Taurus has been associated with the image of a bull (right in Figure 3.1). These meanings are *charged* positively, neutrally or negatively, to varying degrees. For example, in modern astrology Taurus signals such attributes as 'creativity', 'affectionate', and 'grasping'.

The selection, arrangement, meaning and valuation of constellations may vary across place and over time. For example, some stars are visible only from specific locations, but this may change – 'The Southern Cross' was visible in the northern hemisphere before the fifth century. The meanings of a constellation may also change. For example: the Zuni people of New Mexico call the Pleiades cluster 'seed stars', as their position was traditionally used to determine the time of the year to plant seeds; and Pleaides is the logo of the car manufacturer Subaru, whose advertising attempts to associate the symbol with such notions as 'reliability'. The constellations themselves also vary, reflecting differences in *cosmology* or worldview. For example, Figure 3.2 shows Aldebaran, a star in Taurus, located within constellations from (left to right) Inuit, Korean and Maori cultures.[1]

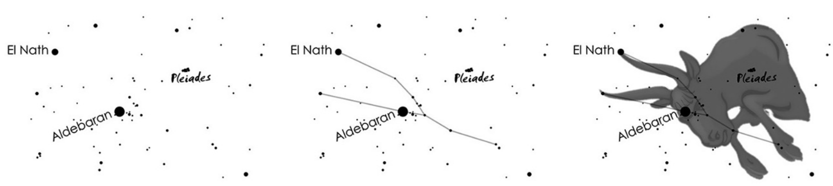

FIGURE 3.1 Taurus – some stars before constellating; stars constellated into Taurus; overlaid with image of bull (Northern hemisphere view)

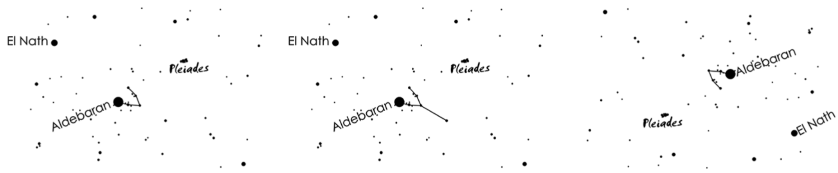

FIGURE 3.2 Aldebaran in constellations from Inuit, Korean and Maori cultures (hemisphere view is that of each culture)

LCT concepts

There are limits to any analogy, but the astronomy example offers a way into understanding the LCT approach to analyzing practices.[2] Cosmological analysis is centred on the five words italicized above:

- *clusters* are groupings of nodes (such as ideas, beliefs or practices);
- *constellations* are larger grouping of nodes that may include clusters;
- *condensation* is how nodes, clusters and constellations are imbued with meanings;
- *charging* describes the valuations given to nodes, clusters and constellations; and
- *cosmology* refers to the organizing principles underlying the selection, arrangement and valuation of nodes in a constellation, which are revealed by analyzing their *legitimation codes*.

Reflecting its sociological nature, LCT holds that a constellation has coherence from a particular point in social space and time, to actors with a particular cosmology, and that cosmologies (and so constellations) are subject to contestation, vary across contexts, and change over time (Maton 2014: 148–70).

This description is intentionally abstract, to reflect the wide applicability of cosmological analysis. The constellation being analyzed may be a scientific theory, religion, political system, ideology, sport, dance, song, machine, etc. – its nodes may be ideas, beliefs, institutions, body movements, sounds, machine parts, etc. Similarly, analysis may focus on many different issues about these constellations, using different cosmological concepts. Here we shall explore relations among stances using only the concepts of *clusters* and *constellations*. We shall not explore the nature of the meanings being related (using *condensation* and *charging*) nor reveal the underlying principles generating, maintaining and changing stances (*cosmologies*). Our focus is a *constellation analysis* of how stances are related together, rather than a *cosmological analysis* of the organizing principles underlying those relations.[3]

Constellation analysis can itself be used in different ways. For example, Maton (2014: 148–70) illustrates a synchronic analysis of ideas. Analyzing claims by advocates of constructivism, Maton shows they construct two constellations of stances on curriculum, pedagogy, assessment and many other issues, that are given such labels as 'student-centred' and 'teacher-centred'. Relations *within* each constellation are constructed as essential: choosing one stance is viewed as choosing all other stances in the same constellation. Relations *between* the constellations are constructed as oppositional: one cannot select stances from both. The two constellations are also portrayed as the only options available. Maton argues that these relations have effects, such as narrowing what is viewed as possible in education by excluding stances either outside or spread between the constellations. Similarly, Glenn (2016) analyzes beliefs about climate change, showing how different groups of people constellate different ideas together and charge those ideas differently, in ways which mean they are more or less open to scientific evidence for climate change.

Another way of using constellation analysis is to explore how stances are selected, linked and given meaning over time to build practices. For example, Lambrinos (2020) reveals how ballet teachers bring together sets of behaviours, dispositions and movements to teach both dance and how to be a dancer. Such analysis can show how clusters or even whole constellations are condensed into a new node, which can then be constellated with more nodes. Figure 3.3, for example, illustrates how a ballet teacher teaches an exercise called 'springs' by linking the instruction 'jump' with other instructions ('sink', 'feet in 1st position', etc.), where 'jump' (solid black in Figure 3.3) has itself been condensed with meanings ('powerful', 'straight legs', etc.). In this way, Lambrinos shows how words, gestures and movements are brought together to create complex constellations. Other studies focus on the building of values in texts. For example, Tilakaratna and Szenes (2020) show how successful student 'reflective writing' assignments cluster and condense meanings to align with disciplinary values, and Doran (2020) reveals the rhetorical strategies of a highly influential text that cluster, condense and charge values to effect change within an intellectual field.

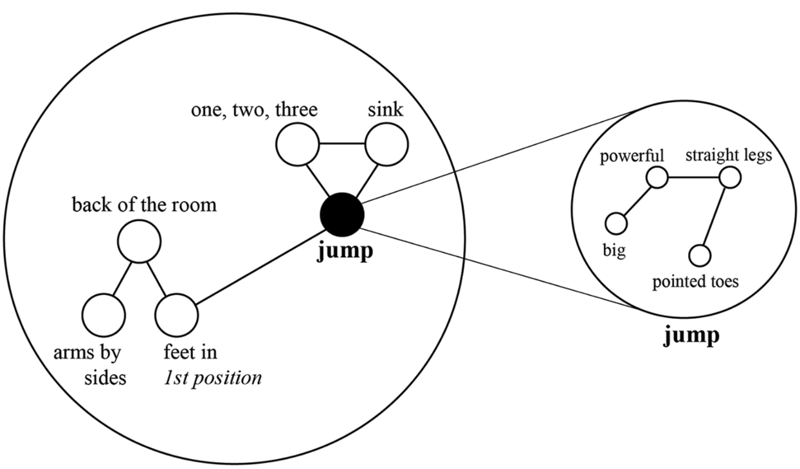

FIGURE 3.3 Example of constellating and condensing movements in ballet teaching (Lambrinos 2020: 91)

However, constellation analysis is still in its infancy. One area for development is identifying different *kinds* of relations within a constellation. Thus far, studies have mostly focused on differences among constellations in terms of their cosmologies or underlying legitimation codes (Maton 2014: 148–70). As yet few studies explore different relations *within* a constellation.[4] In this chapter we contribute to exploring this issue.

Three simple distinctions

To illustrate the significance of different relations among ideas, we shall make three simple distinctions relevant to our analyses in this chapter, between 'independent' and 'dependent' links, 'base' and 'supplementary' clusters, and 'assembling' and 'aggregating' when building constellations.

First, we distinguish between:

- *independent links,* where the meanings of a node or cluster are independent of other nodes or clusters in the constellation; and
- *dependent links,* where the meanings of a node or cluster depend on relations to other nodes or clusters in the constellation.

For example, in the explanation of tides (below), the node 'The Earth is divided into water and solid components' does not depend on other nodes in the explanation, generating independent links with those nodes. It does not depend, for example, on the idea that 'The Moon has gravity, which is stronger the closer things are to the Moon'. This is not to suggest that the ideas expressed by such nodes are always independent; they will be related to ideas in *other* constellations, such as explanations of the Earth, planets, etc. However, this highlights where nodes create independent links with other nodes *within the constellation in question*. In contrast, in the tides explanation a node that describes the different gravitational pulls of the Moon on the water and solid components of the Earth links to two other nodes in the explanation – 'The Earth is divided into water and solid components' and 'The Moon has gravity, which is stronger the closer things are to the Moon' – by describing their implications when combined. It thereby generates dependent links with those two nodes within the constellation.[5]

Second, we distinguish between:

- a *base cluster* or set of nodes that creates a basic version of the constellation; and
- *supplementary clusters* or sets of nodes that serve to elaborate, augment and refine the base cluster.

For example, in the explanations of tides, the textbooks and teaching we analyze draw on four nodes to create a basic explanation of tides (the base cluster), and elaborate on this explanation by employing other clusters of nodes to explain daily variation in tides, and 'spring' and 'neap' tides (two supplementary clusters). Together all three clusters constitute the explanation, but one cluster offers a 'base' on which the other clusters elaborate. This is *not* a distinction between fundamental and peripheral, essential and inessential nodes, but rather highlights two roles played by clusters of nodes in the explanations we analyze in this chapter.

Third, we distinguish between two ways that constellations unfold over time:

- *assembling*, where nodes and clusters develop in a linear and incremental fashion; and
- *aggregating*, in which nodes or clusters are developed separately, in a multilinear fashion.

In *assembling* the constellation is likely to grow from one origin; in *aggregating* the constellation involves multiple separate parts, each of which may be assembled on its own before being combined.[6] As we shall illustrate, the tides explanation appears to lend itself to assembling nodes and clusters in a linear manner, while the seasons explanation has a range of potential ways of aggregating nodes and clusters together.

These three distinctions are not the only relations within constellations created by scientific explanations, let alone within constellations generally. Our aim is not to conceptualize all relations among ideas but to make intentionally simple distinctions that demonstrate a simple point: different relations among ideas matter. Conversely, not all constellations involve these distinctions: they may comprise only dependent or independent nodes, have no base or supplementary clusters, and remain static. The distinctions are thus not generic characteristics – they reflect our specific focus and aim.

Analyzing two explanations: Of tides and seasons

Our focus is on analyzing two scientific explanations. Our aim is to show that, though they appear similar, the explanations involve different relations among ideas that may be significant for how they are taught. Both are core topics in Year 7 of secondary school science in New South Wales (NSW), Australia. Both concern widely-known phenomena in the natural world: the tides and the seasons on Earth. Both phenomena appear *prima facie* simple: water reaches higher and lower through the day (tides) and the temperature goes higher and lower over the year (seasons).[7] However, we shall show that explanations of tides and seasons involve complex constellations of ideas brought together in distinctive ways.

We analyze each explanation in two ways. First, we create *schematic constellations* of the logic of each explanation according to textbooks aimed at Year 7 secondary school science in NSW. This is not analyzing how textbooks sequence their explanations or build constellations; it does not describe a specific textual or pedagogic expression. Rather, a 'schematic constellation' is a synchronic representation of key nodes and how they are logically related – a snapshot of *the logic of the explanation*. To create the constellation, we identify nodes and links that the textbooks contain or assume in order to make sense.[8] The resulting constellation diagrams are akin to transit maps that show not specific journeys but rather the roads, stations, connections, routes, etc. They are a composite from analyses of textbooks known as: Oxford Insight (Zhang *et al.* 2013), Nelson iScience (Bishop *et al.* 2011), Pearson (Rickard 2011), Core Science (Arena *et al.* 2009), and Science World (Stannard and Williamson 1995).

Second, we create *pedagogic constellations* showing how each explanation is taught by the same teacher during the same unit of secondary school science.[9] Our focus is to explore whether the logic might shape the pedagogic, that is whether relations among ideas in the logic of an explanation might affect how that explanation is taught. To return to the metaphor, these pedagogic constellations describe specific journeys across the terrain shown by the schematic constellations.

This analysis does not, of course, offer a comprehensive account of how tides and seasons are explained in schooling. As stated above, constellations often vary across time and space. In other contexts, different explanations may include more or fewer nodes and different links. The analysis is thus limited to our empirical examples. Moreover, our examples are not intended to demonstrate best practice and whether the explanations are accurate or complete is not our concern. Our aim is simply to explore how relations among ideas are expressed and their potential significance.

In summary, we shall argue that the schematic constellation for tides is less complex than that for seasons. One effect of this difference is, we suggest, shown by pedagogic constellations: the tides explanation lends itself to an *assembling* form of teaching that proceeds in a linear fashion through successive clusters, while the seasons explanation lends itself to an *aggregating* form of teaching that proceeds in a more patchwork fashion. We conjecture that the forms taken by relations among ideas in the logic of an explanation (schematic constellation) may shape how the explanation is likely to be taught (pedagogic constellation). To reach these conjectures, we analyze tides and of seasons, in turn.

Explaining tides

Schematic constellation of textbooks

From analyses of sections on 'tides' in the five textbooks, we developed a composite of key nodes in their explanations. We begin by summarizing these nodes as simply as possible, in our own words. In **bold** are words included in the diagrams that follow.

A. The Earth is divided into **water and solid** components.
B. The **Moon** has **gravity**, which is stronger the closer things are to the Moon.
C. Together node A (water and solid) and node B (Moon's gravity) mean that the **Moon's** gravitational **pull** is strongest for the water on the Earth closest to the Moon, less strong for the Earth's solid, and weakest for the water on the Earth furthest from the Moon.
D. Node C produces bulges of water on the parts of the Earth that are closest and furthest away from the Moon, which we experience as '**high** tides', and no

bulges on the parts of the Earth that are neither closest nor furthest, which we experience as '**low** tides'.

E. The **Earth rotates**.
F. Earth's rotation (node E) combined with the bulges of water created by the Moon's gravity (node D) leads to the experience of **daily variation** of tides as the Earth moves through the bulges.
G. The **Moon orbits** the Earth.
H. The **Sun's gravity** pulls on the water and solid components of the Earth.
I. Combining the Moon's orbit of the Earth (node G) and the Sun's gravitational pull (node H) with the daily variation of tides (node F) leads to variation in the size of tides. When the Sun and Moon line up, the tides vary the most (highest highs and lowest lows), which is known as the '**spring** tide'; and when the Sun and Moon are perpendicular, the tides vary the least (with the lowest highs and highest lows), which is known as the '**neap** tide'.

Figure 3.4 represents this description as a constellation diagram. Nodes which generate *independent links* are in squares and nodes which generate *dependent links* are in

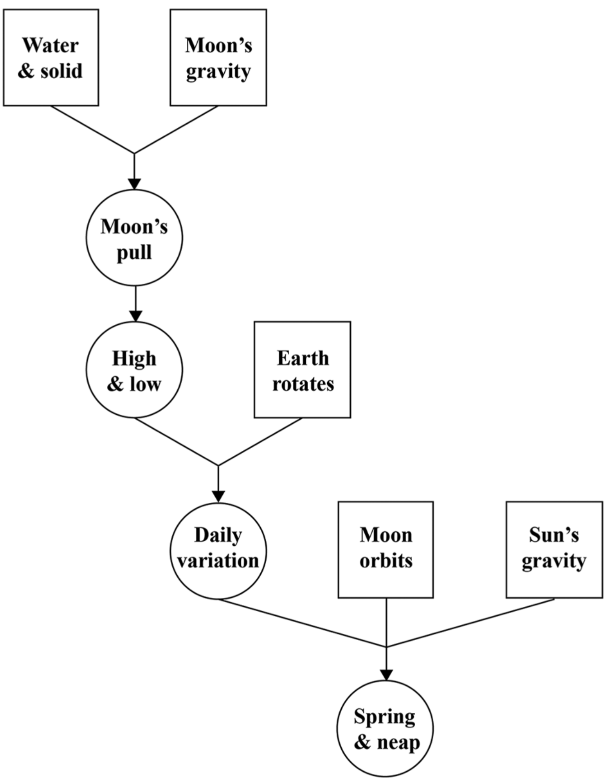

FIGURE 3.4 Schematic constellation of the tides explanations across textbooks

circles. Dependent links are shown by lines with arrows that indicate the direction of implication.

Links, clusters and form

Though 'tides' may seem a simple empirical phenomenon, its explanation is relatively complex, involving different links and clusters. In terms of links, the schematic constellation is characterized by both independent and dependent relations among nodes. As Figure 3.4 shows, the schematic explanation begins with two nodes that create independent links: the Earth's components of **water and solid** and the **Moon's gravity** are not dependent on other nodes *in this explanation*. In contrast, how the **Moon's pull** affects Earth's components comprises implications of bringing together those two nodes, generating dependent links (shown by the arrow). The node introducing **high and low** tides outlines the implications of the Moon's pull for creating bulges of water. This reaches the notion of 'tides'. That the **Earth rotates** is independent. The **daily variation** of tides creates a dependent link by describing implications of bringing together the **Earth's rotation** with **high and low** tides. That the **Moon orbits** the Earth and the **Sun's gravity** are both independent. To reach the notions of **spring and neap** tides, these two nodes are combined with **daily variation**, creating dependent links with all three nodes. In summary, a series of independent nodes establish factors or phenomena and dependent nodes relate those phenomena together.

In terms of clusters, the schematic constellation for the textbooks' explanation of tides comprises a *base cluster* and two *supplementary clusters*. As shown in Figure 3.5a, the top four nodes form a base cluster that creates a basic explanation of tides. The two supplementary clusters are *successive* in that each progresses from a logically preceding node. As shown by Figure 3.5b, the cause of **high and low** tides is the starting point

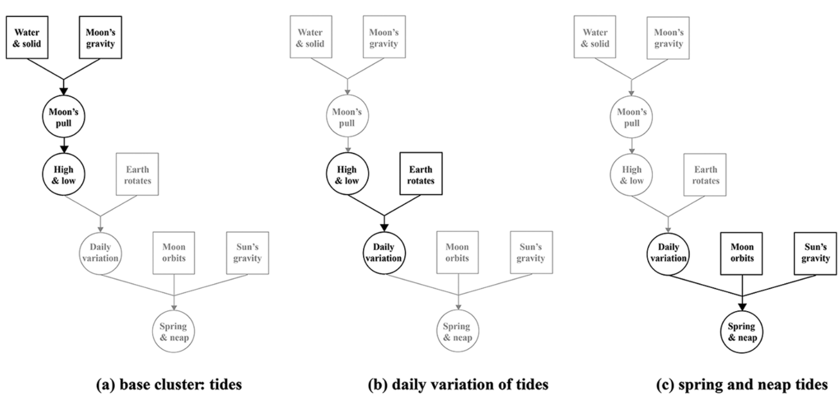

FIGURE 3.5 Schematic constellation for tides – base and supplementary clusters

for a supplementary cluster with the **Earth's rotation** that augments the basic explanation to reach **daily variation** in tides. As shown by Figure 3.5c, **daily variation** is part of a second supplementary cluster with the **Moon orbits** and **Sun's gravity** that elaborates the preceding explanation to describe **spring and neap** tides.

In terms of its form, the schematic constellation does *not* show how the explanation unfolds over time. However, it does reveal that its logical links are relatively linear: the simple explanation of the base cluster is augmented through successive supplementary clusters. There are no parallel clusters elaborated or large numbers of separate nodes described which then require integration. The implications of this relative simplicity will, however, only become apparent in contrast with our analysis of 'the seasons', further below.

A pedagogic constellation for tides

We now turn to how an explanation of tides was taught in a secondary science classroom in comparison to this schematic constellation. Our example is part of a lesson within a unit on 'Earth and space sciences' from Year 7 of secondary school, NSW, that explores such topics as 'day and night', 'the seasons' and 'tides'. We focus on a lesson phase in which the topic of 'tides' is introduced by the teacher and a video is played that details an explanation.

Introducing the topic

Immediately prior to addressing 'tides', the teacher shows a video about the Moon and the Earth. She then asks the class what might cause tides. A student suggests 'the Moon's gravitational pull', which was mentioned in the video, and the teacher elaborates:

> Yes, very good. So, because the Moon has gravity it actually pulls the mass of water towards itself. Wherever the Moon is, that's where the high tide will be and wherever the Moon isn't, that's where the low tide will be.

So, the teacher links the **Moon's gravity** and the Earth's **water and solid** composition by how the **Moon's pull** affects the water and thence to a simple description of **high and low** tides. She thereby provides a succinct, Moon-focused equivalent to the base cluster outlined above (Figure 3.5a) before starting the video on tides. As this highlights, pedagogic constellations may form part of a series in which teachers and student build on preceding discussions or look ahead to future topics. They venture onto the terrain shown by the transit map from where they have just been, in this case discussing the Moon.

A video explanation

The teacher plays a video entitled 'Watching the tides' in which an astronomer explains the causes of tides.[10] The video begins by summarizing key factors:

> Tides are caused by the gravitational pull of the Moon and the Sun and the rotation of the Earth. The Earth is not a solid sphere like we think. It's actually kind of squishy. Especially this layer of water we have on the outside – the oceans.

This is accompanied by an animation showing the Moon orbiting the Earth. It thus begins by highlighting: the **Moon's gravity**, the **Sun's gravity**, the **Earth's rotation**, the Earth's composition as **water and solid**, and the **Moon's orbit**. Thus, as shown by Figure 3.6a, the video begins by introducing the five independent nodes.[11]

The video then begins creating dependent nodes that link these independent nodes together:

> So the gravity of the Sun and the Moon actually kind of squeeze or stretch the Earth and its oceans out into a couple of bulges. One under the Moon, one on the other side of the Earth.

This links 'the Earth and its oceans' (**water and solid**) with the **Sun's gravity** and the **Moon's gravity** to explain that the oceans are pulled into bulges, while the accompanying animation shows bulges on the parts of the Earth closest to and furthest from the Moon, creating a simple version of the node stating that the **Moon pulls** on Earth's components differently. The video continues:

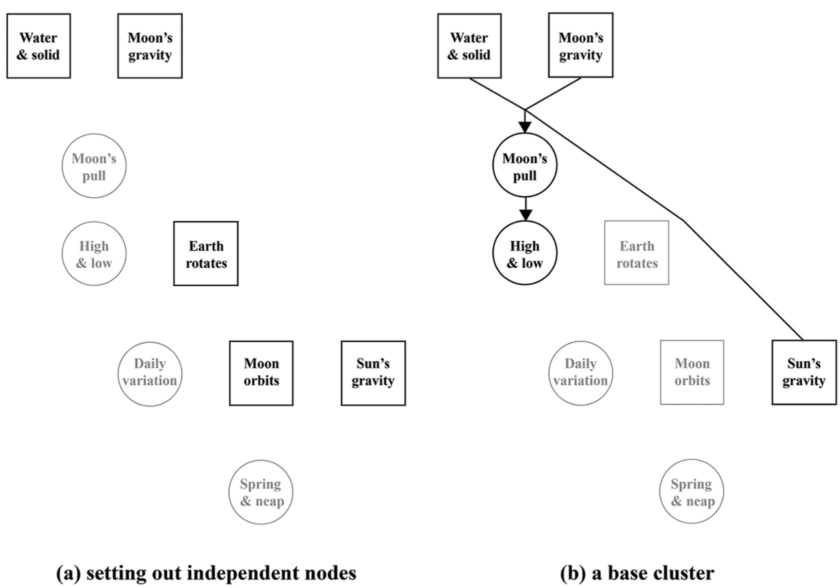

FIGURE 3.6 Pedagogic constellation for tides – independents and base cluster

> And as the Earth rotates over the course of the day, you, standing on the surface of the Earth, move along with the Earth's surface into these bulges. And we experience that as the rising and lowering tides.

This is a simple version of **high and low** tides. As illustrated by Figure 3.6b, the video has now outlined a base cluster echoing that of the schematic constellation. There are two main differences. First, the **Sun's gravity** has been recruited verbally into the base cluster, though the animation does not include the Sun and its role is not discussed. Second, the key attribute of the **Moon's gravity** – that it is stronger the closer things are – has not yet been mentioned. This issue is, though, immediately discussed (emphasis added):

> Now it's easy to see how on the side facing the Moon or the Sun you can get this bulge of ocean. You can imagine the gravity pulling the oceans up into a bob or a bubble. But it's not as easy to understand why there's a bulge on the other side as well. And the easiest way to describe that is: *the Moon's gravity is stronger, of course, the closer you get to it*. So, on the side of the Earth close to the Moon, the Moon has a stronger pull. So while the oceans on the Moon side get pulled more strongly than the general Earth does, on the other side it's kinda opposite. The pull on the oceans on the far side are less than the pull on the Earth. So that far bulge actually gets created … think of it as the Earth being pulled out from under the oceans, a little bit.

The video thereby completes the base cluster (Figure 3.6b). The attribute of the **Moon's gravity** (in italics) has been added and brought together with the Earth's composition as **water and solid** to describes implications for the **Moon's pull** on those components, and so the creation of bulges of water or **high and low** tides.

In short, the video first creates a preliminary, intuitive version of the base cluster and then uses the counter-intuitive nature of the Moon's gravity creating a bulge on the *far* side of the Earth as a way of completing that basic explanation. Next, the video links **high and low** tides with the **Earth's rotation** to describe implications for **daily variation** of tides:

> You get two high tides a day because as the Earth rotates, we rotate through these two bulges.

As shown in Figure 3.7c, this echoes the first supplementary cluster of the schematic constellation. The video then creates the second supplementary cluster – Figure 3.7d. The role of the **Sun's gravity** is shown in the accompanying animation and linked with the **Moon's orbit** to introduce '**spring** tide' **and** '**neap** tide':

> Both the Moon and the Sun play a part in tides. Each one pulls. And when the Sun and the Moon combine their forces – that is, when they're both acting together – we get much stronger tides than usual. Higher highs and lower

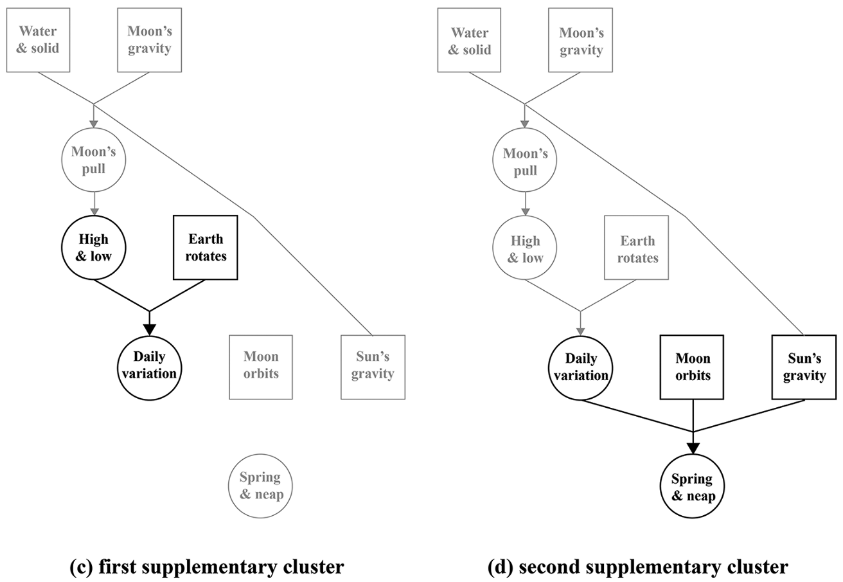

FIGURE 3.7 Pedagogic constellation for tides – supplementary clusters

> lows – we call these 'spring tides'. The name 'spring tide' doesn't have anything to do with the season of spring, but we get them about twice a month at new Moon and at full Moon, when the Earth, the Moon and the Sun are all lined up and the gravity of the Sun and the Moon are acting together. 'Neap tide' is when the tidal effects of Sun and Moon are kind of cancelling each other out or making each other not as extreme. And that happens around first and third quarter phases of the Moon. The Sun is in one part of the sky and the Moon is ninety degrees around and they're kind of pulling in different directions. So you get lower highs and higher lows during the neap tide.

This is the end of the video's explanation of tides, completing the constellation.

The pedagogic constellation thereby contains the same nodes, links and clusters as the schematic constellation. The form of constellation building here is what we defined as *assembling*. After introducing the independent nodes, the video selected and brought together, through dependent nodes, a subset to create a base cluster. It then added another independent node and drew out its implications through a dependent node, repeating this move to complete the explanation. It set this out in a linear and incremental fashion, accreting new nodes and linking them to existing nodes. A further attribute is how closely the pedagogic ordering of the nodes and clusters in the video matches the logic of the schematic constellation. There are many good reasons why teaching may differ from the logic of an explanation. For example, an educator may choose to build on what they have been discussing (as the teacher did in her introduction) or to wait before introducing an attribute in order to begin from shared experiences or intuitive common sense (as the video did here).

However, in this case the ordering remains remarkably similar. As we shall see, this contrasts with the unfolding of the explanation of seasons.

Explaining seasons

Schematic constellation of textbooks

From analyses of explanations of 'seasons' in the five textbooks, we developed a composite description of their key nodes, which we again state as simply as possible, in our own words, and with **bold** indicating nodes in constellation diagrams (starting with Figure 3.8).

A. The **Earth is tilted** on its axis at an angle of 23.4 degrees.
B. The Earth is divided into northern and southern **hemispheres**.

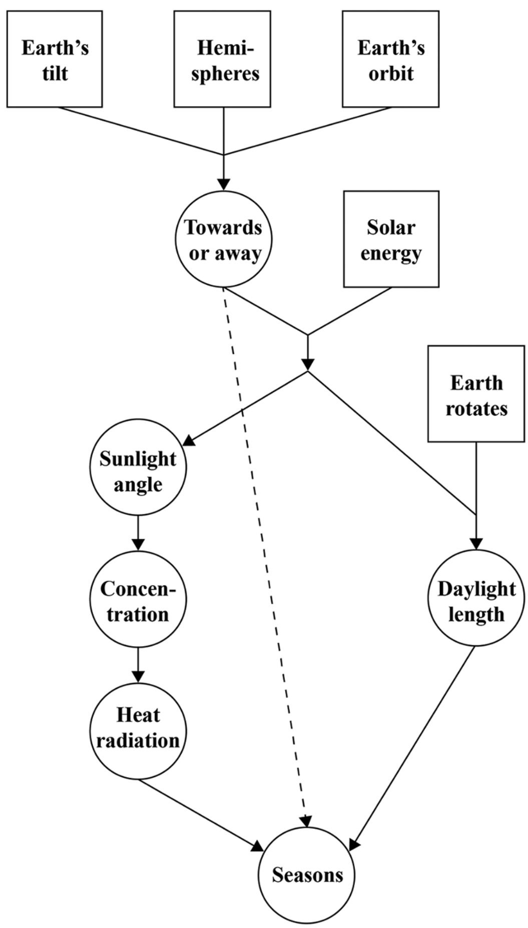

FIGURE 3.8 Schematic constellation of the seasons explanations across textbooks

C. The **Earth orbits** the Sun.
D. The Earth's tilt (node A), division into hemispheres (node B), and orbit of the Sun (node C) together mean that the Earth's northern and southern hemispheres point **towards or away** from the Sun at different times of the year.
E. The Earth receives **solar energy** from the Sun's rays.
F. That hemispheres point towards or away from the Sun (node D) and that the Earth receives solar energy from the Sun (node E) mean that **sunlight** hits each hemisphere at different **angles** through the year: when a hemisphere is pointing towards the Sun the angle of its rays are more direct; and when a hemisphere is pointing away from the Sun the angle of its rays are less direct.
G. Different angles of sunlight (node F) means that the **concentration** of light changes in each hemisphere through the year: when a hemisphere is pointing towards the Sun, the more direct sunlight it receives is concentrated in a smaller area; and when a hemisphere is pointing away from the Sun, the less direct sunlight it receives is concentrated in a larger area.
H. Differences in concentration of sunlight (node G) means that the amount of **heat radiation** in each hemisphere varies through the year.
I. The **Earth rotates**.
J. That hemispheres point towards or away from the Sun (node D), the Earth receives solar energy (node E) and the Earth rotates (node I) together mean that different parts of the Earth experience different **length of daylight** at different times of the year.
K. Variations in heat radiation (node H) and/or daylight length (node J) leads to variations in temperature in each hemisphere through the year that are called '**seasons**'. This can also be more simply put as: that hemispheres point towards or away from the Sun (node D) leads to variations in temperature in each hemisphere through the year that are called 'seasons'.

Links, clusters and form

Figure 3.8 represents the description as a schematic constellation. Like that for tides, the constellation involves nodes that generate both independent (squares) and dependent (circles) relations with other nodes. Also like tides, it exhibits a base cluster and two supplementary clusters. However, there are significant differences in how the seasons constellation relates together its constitutive ideas.

The schematic constellation begins with three independent nodes describing **Earth's tilt**, **hemispheres** and **orbit**. These nodes are brought together to describe their implications for hemispheres pointing **towards or away** from the Sun, generating dependent links with all three. From here one can proceed directly to implications for variations in temperature in hemispheres through the year, reaching **seasons** through a dependent link. As shown in Figure 3.9a, this represents a base cluster. There are then two supplementary clusters that develop this explanation. At this point the constellation becomes more complex than that of tides, in two ways.

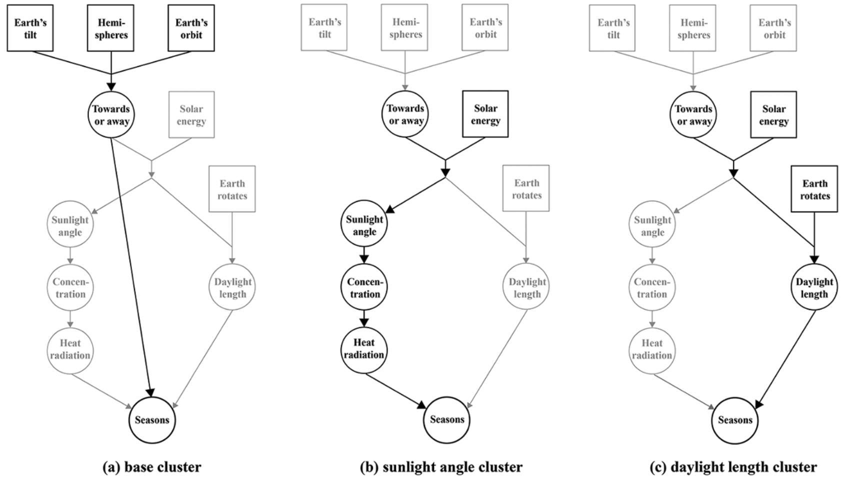

FIGURE 3.9 Schematic constellation for seasons – base and supplementary clusters

First, the supplementary clusters offer parallel routes through the logic of the explanation. What we term the 'sunlight angle cluster' recruits the nodes highlighted in Figure 3.9b. This brings together the node describing hemispheres pointing **towards or away** from the Sun with the independent node that the Earth receives **solar energy** from the Sun's rays to describe their implications for variations in the **angle of sunlight** received by hemispheres. It then elaborates implications of these variations in sunlight angle for the **concentration** of sunlight, the implications of variations in concentration for **heat radiation**, and in turn the implication of variations in heat radiation for temperatures, which reaches **seasons**. A second supplementary, which we term the 'daylight length cluster', is shown in Figure 3.9c. This too brings together the nodes on pointing **towards or away** from the Sun and **solar energy** but this time adds the independent node that the **Earth rotates** to describe the implications of these three together for variations in the **length of daylight** in hemispheres through the year. It then draws out the implications of these variations in daylight length for temperatures, reaching **seasons**. Crucially, these two clusters are not successive but parallel: each cluster reaches 'seasons' separately. The logic allows seasons to be explained through either cluster or both clusters together.

A second difference with tides is that the supplementary clusters do not elaborate the base cluster in the same way. In tides, each supplementary cluster adds to the logically preceding cluster, proceeding from 'tides' to 'daily variation in tides' to 'spring and neap tides'. In contrast, here the supplementary clusters 'unpack' the implications of hemispheres pointing **towards or away** from the sun for creating **seasons**. They are akin to focusing in on the long dashed arrow in Figure 3.9a and providing more detailed explanations of that relation. Put another way, the supplementary clusters for tides add relations to new destinations along one route (tides – daily variation – spring/neap) while the supplementary clusters for seasons clarify and deepen an existing relation by adding new routes to the same destination (seasons). These routes show the complexity latent within the link between '**towards or away**' and '**seasons**'.

In short, the seasons constellation is less linear and successive than that of tides, offering more options for navigating its logic to create an explanation. We now turn to explore how this difference might be reflected in how explanations of the seasons are taught in a classroom.

A pedagogic constellation for seasons

The example we discuss comprises a lesson on 'seasons' in the same Year 7 secondary school classroom, immediately preceding the lesson on tides analyzed above. The teacher begins the topic by showing how ripe the topic is for misunderstandings.[12] She plays a 'vox pop' video in which adults are asked for causes of seasons and suggest such mistaken beliefs as the equator, changing distance from the Sun, and Earth's elliptical orbit. The teacher states this shows that 'You have to think carefully about what we're doing'. Unlike 'tides', she thus begins by highlighting the complexity of the constellation. This complexity, we argue, is reflected in the number of times she takes the class on different routes to reach an explanation. Specifically, she takes the class through: (a) a 'daylight length' route; (b) a 'sunlight angle' route; (c) a 'base cluster' route; and (d) a composite route that includes ideas from all three clusters. These routes are discrete: they are separated by class discussions of related ideas (such as the names of longest and shortest days) or by student questions (such as whether leap years affect the Earth's orbit) that are not woven into explaining the seasons. We shall go through each explanation briefly, using the schematic constellation as a basis for comparing these routes.

(a) *A 'daylight length' route*

The teacher begins from where the previous lesson ended, with changes in the length of days through the year:

> In the summer, days are longer, and in the winter, days are shorter. When the days are longer, that means there is more time for the Sun to heat the Earth. So that means that the temperature is warmer. Okay?

In terms of the schematic constellation, the teacher begins with the effects outlined as '**daylight length**' and '**seasons**'. She then refers to an experiment students conducted in a recent lesson that involved heating a wooden block with a lamp to model the effect of the Sun's rays on the Earth:

> So remember that experiment we did when we put the thermometer in the block? As the time at which we kept that light on the block increased the temperature. It's the same thing that happens with days. When the days become shorter, we have overall lower temperatures. Because we have long days in

summer and short days in winter, we get higher temperatures, we get lower temperatures.

This brings in **solar energy** from the Sun. The teacher asks: 'why do we have some long days and some short days?'. A student answers 'because the Earth is **tilted**', and the teacher responds:

> Good. So it's got to do with the tilt of the Earth and depending on which part is tilted closer to the Sun will determine which will have longer and shorter days.

This is to say that depending on which of Earth's **hemispheres** is brought by **Earth's tilt** to be pointing **towards or away** from the Sun will determine the **daylight length** in that hemisphere.

Figure 3.10a, like all constellation diagrams in this analysis, shows the ideas and relations among ideas of each explanation rather than the exact sequencing of nodes in the teacher's discourse. As the Figure illustrates, the teacher offers here a simple 'daylight length' route through the explanation. Taken as a whole, it brings together **Earth's tilt** and **hemispheres** to reach **'towards or away'**, which, bringing in the

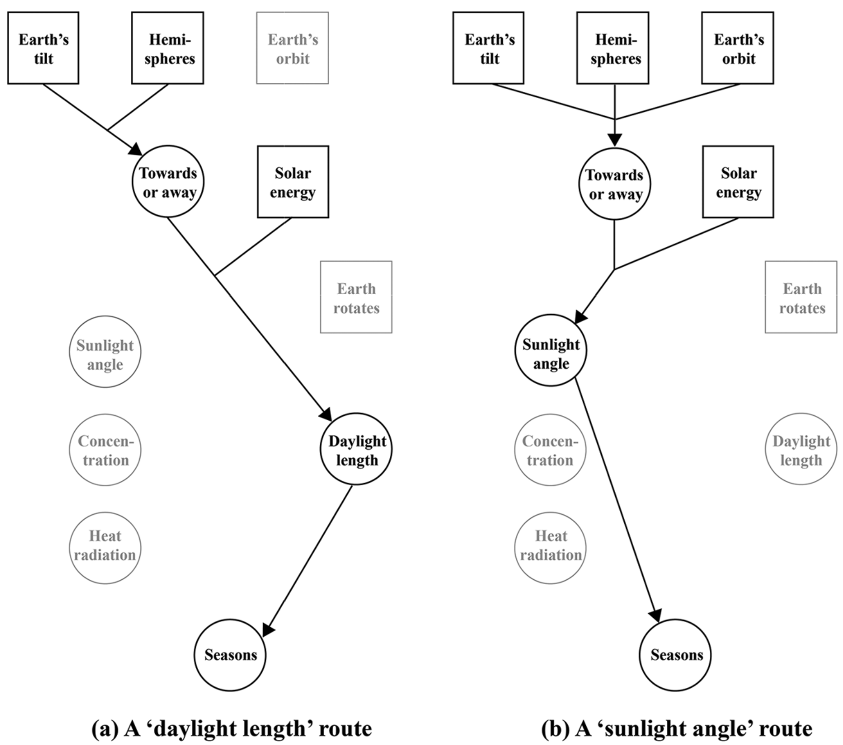

FIGURE 3.10 Pedagogic constellations for seasons – 'daylight length' and 'sunlight angle' routes

aforementioned **solar energy,** reaches **daylight length** and thence **seasons**. At this stage, the teacher did not include **Earth's orbit** and **Earth's rotation**.

(b) ***A 'sunlight angle' route***

In the next version of the explanation, the teacher shows an animation entitled 'What causes Earth's seasons', muting the sound and adding her own commentary (to which we have added the nodes discussed in brackets):[13]

> … what we're looking at here is obviously the Earth spinning on its axis [**Earth rotates**] and you can see that that axis is about 23.5 degrees from what could be the "theoretical midline" of the Earth [**Earth's tilt**]. We know that that axis holds itself. … Now, when the Sun's rays [**solar energy**] hit the Earth, the Earth has that also other "theoretical midline", the equator, that breaks it into half: northern hemisphere and southern hemisphere [**hemispheres**]. Okay? We're in the southern hemisphere and at some times the sunlight will strike, in this case, the southern hemisphere at that 90 degree angle [**sunlight angle**]. All right? And here, this is what we can sometimes call an 'oblique' … or 'glancing' [**sunlight angle**].

The first node, **Earth rotates**, is mentioned to direct students to watch the animation and not woven into the explanation. The rest – **Earth's tilt**, **solar energy**, **hemispheres** and **sunlight angle** – are introduced first as factors to be related. She then brings them together:

> Now, when this moves around the Sun [**Earth's orbit**], and holds its axis [**Earth's tilt**], 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 [**towards or away**]. … now we're on the back side of the Sun. We've got spring and autumn [**seasons**]. Now we're on the opposite side. Now the northern hemisphere has summer and the southern hemisphere has winter [**seasons**]. Now, we come out to the "fourth side" of the Sun, we get autumn and spring split around [**seasons**].

The teacher then sums up this explanation with a PowerPoint slide showing the Earth (with equator and axis shown), the Sun and its rays hitting the Earth: 'So we know the Sun is hitting the Earth [**solar energy**]. We know that some parts of the Earth [**hemispheres**] will be getting the full force and some will getting those glancing rays [**sunlight angle**]' and then emphasizes that 'The thing that will change is our position in relationship to the Sun' [**towards or away**].

As illustrated by Figure 3.10b, taken as a whole this offers a 'sunlight angle' route through the explanation. In combination with the animation, the teacher shows that **Earth's tilt**, **hemispheres** and **orbit** mean that different hemispheres point **towards or away** from the Sun which, when struck by **solar energy**, means there are differences in **sunlight angle** that create **seasons**.

(c) ***A 'base cluster' route***

The third explanation comprises three activities: discussing a video animation, students writing in their workbooks, and students drawing a diagram. First, the teacher shows a video animation of the Earth and the Sun and highlights that the Earth is 'moving around the Sun' (**Earth's orbit**), that **Earth's tilt** is not changing, and that these together mean the **hemispheres** change their relative position to the Sun (**towards or away**). The teacher sums this up as: 'This is why we end up with opposite seasons. Because of that tilt in our axis puts us in different positions in relationship to the Sun'. As Figure 3.11c shows, this echoes the base cluster of the schematic constellation.

Second, the teacher asks students 'to write one or two sentences that explains how the Sun and the Earth create seasons'. She plays the animation again while students write for several minutes, before soliciting their answers. The first student answer is that 'The tilt of the Earth on a 23.5 degree angle and the orbit around the Sun makes the Earth have seasons', which is to state that **Earth's tilt** and **Earth's orbit** lead to **seasons**. This does not include **hemispheres** or pointing **towards or away** from the Sun and the teacher responds: 'It doesn't quite explain, though, *why* we get the different seasons'. The next two answers provide what she is seeking:

STUDENT The Earth is always on a 23 ½ degree tilt. This tilt remains the same as we orbit the Sun but the area facing the Sun is different [**towards or away**]. This causes the seasons.

TEACHER Fantastic. I like that. Very good. Who else has one?

STUDENT The seasons are created by the Earth's 23.5 degree tilt. When the northern hemisphere is tilted towards the Sun, it is summer. As the Earth orbits the Sun the tilt stays the same but the side [**hemispheres**] that's tilted towards the Sun changes [**towards or away**], making it winter in the northern hemisphere because it's furthest away.

TEACHER Fantastic, I like that. That's a good one. All right. Hopefully yours says something similar to that.

The first answer adds the node of pointing **towards or away** from the Sun and the second answer adds both that node and **hemispheres**. Once these responses complete the constellation that she had set out, the teacher moves on.

Finally, a simpler version of the constellation is repeated again while the students draw a diagram. The teacher shows a simulation in which she can move the Earth to different positions around the Sun. Students are told to draw a diagram of the Sun and the Earth for one season. 'The key point here', she emphasizes, 'is to make this an accurate diagram'. Through questions, the teacher solicits from students 'the things we cannot be sloppy on in this diagram': 23.5 degrees **tilt** and axis, lines for the equator to show **hemispheres**, and an elliptical **orbit** around the Sun. Thus, the independent nodes of the 'base cluster' are again emphasized as key factors.

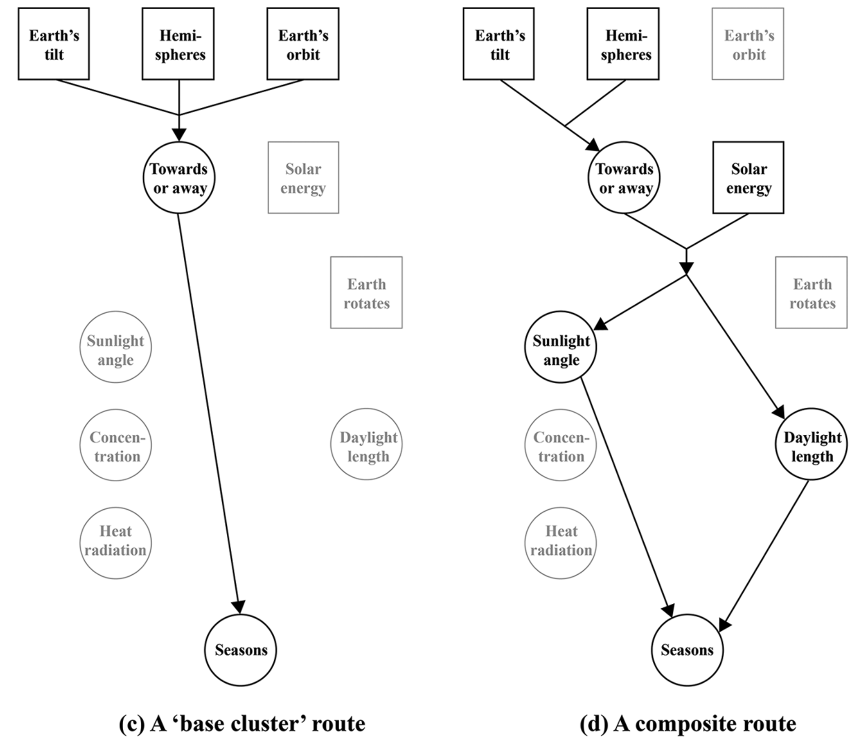

FIGURE 3.11 Pedagogic constellations for seasons – 'base cluster' and combined routes

(d) ***A composite route***

The final explanation comprises a summary spoken by the teacher:

> We know that because the Earth's tilted, that different parts of the Earth will face the Sun at different parts of the year. That difference then in the sunlight striking the Earth will lead to different seasonal variations in temperature, depending on how much the Earth has heated up during the day. The length of our day will also then depend on how far north or south you are from the equator. And that explains why temperatures over the year will change at different locations.

As Figure 3.11d shows this states that **Earth's tilt** means different **hemispheres** – routinely called 'parts of the Earth' through the lesson – will point **towards or away** from the Sun, which means that **solar energy** will strike the Earth in different ways (**sunlight angle**), which leads to variations in temperature (**seasons**), but that this also depends on how much the Earth has heated during the day due to variations in **daylight length**. Taken together, this all explains the **seasons**. So, this explanation includes the 'base cluster' (minus **Earth's orbit**), her 'sunlight angle' route and her 'daylight length' route. In short, it provides a summarizing composite of the three routes she has taken the class on when creating explanations.

Aggregating explanations

Our concern has been not to evaluate this teaching but to explore what it can tell us about relations among ideas. Here, explaining the seasons seems to offer a variety of potential pedagogic constellations. During an hour-long lesson the teacher takes the class on four different routes, focused on 'daylight length', 'sunlight angle', the 'base cluster' (on which she checks students' understanding), and a composite of all three. This involves what we termed *aggregating*: separate clusters are assembled, each on its own, before being combined. Moreover, this aggregating involves node options: some nodes from the schematic constellation were not included: **sunlight concentration**, **heat radiation** and **Earth rotates**. This is, though, not a gap in teaching. The schematic constellation is not a list of essential ideas but rather a composite of all nodes found in the textbooks we analyzed; not all textbooks include all those nodes. There are likely to be sound pedagogic reasons for employing a certain level of complexity and not adding further nodes that may overcomplicate the explanation.

Conclusion

Science is complex – seemingly simple empirical phenomena may require complex explanations. Our argument has been simple: relations among ideas are one aspect of this complexity and constellation analysis offers a way of seeing these relations and analyzing the roles they play in building knowledge. Our analysis of the logic of explanations of tides and seasons that are offered by textbooks aimed at Year 7 science in NSW, Australia, made the simple point that relations among ideas differ even between otherwise seemingly similar sets of ideas. Our analysis of how those explanations were taught in the same classroom highlighted the simple point that differences in how sets of ideas are taught may be related to differences in relations among their ideas. By analyzing their pedagogic constellations in relation to their schematic constellations, we were not arguing that the logic of explanations is an ideal against which teaching should be measured. As we emphasized, there are many sound reasons for teaching knowledge in different sequences to, or in different degrees of detail than shown by schematic constellations. (Indeed, each textbook unfolds its explanation differently to the composite schematic constellation). Rather, our aim was to show that relations among ideas in an explanation may affect how those explanations are taught – in short, the logic may help shape the pedagogic.

To demonstrate this point, we focused on examining simple distinctions between two kinds of links, clusters, and forms of constellation-building. Using these distinctions we showed that the schematic constellation for tides involves a base cluster that is elaborated successively by supplementary clusters, while that for seasons involves parallel supplementary clusters that 'unpack' part of the base cluster and offer different ways of reaching 'seasons'. Put simply, the elaboration of clusters for tides was akin to 'A then B then C', where for seasons it was akin to 'A and/or B and/or C'.

Using the same distinctions we then analyzed how each explanation was taught by the same teacher during the course of a single unit of study. The pedagogic explanation of tides echoed the logic of its schematic constellation: linear and successive clusters of ideas that build on preceding ideas. The pedagogic explanation of seasons also echoed the logic of its schematic constellation: the teacher set out four different selections and arrangements of ideas that offered differing versions. So the two explanations differed in how they were taught by the same teacher. From this analysis we suggested that 'seasons' appears more amenable to variation of which ideas are selected and how they are brought together. In short, these *assembling* and *aggregating* forms of building constellations differed in ways that echoed relations among ideas within the logic of the explanations.

Beyond our modest aims, these insights suggest that constellation analysis may shed light on relations between research, curriculum and pedagogy. By showing how knowledge changes as it is transformed into curricula or taught in classrooms, constellation analysis could open the 'black box' of recontextualization. Following Bernstein (1990), LCT distinguishes between the logics underlying *production fields* that create 'new' knowledge, *recontextualizing fields* that create curriculum, and *reproduction fields* or sites of teaching and learning (Maton 2014: 43–64). Movements of knowledge between fields are held to involve 'recontextualization' – selection, arrangement and enactment of ideas – that restructures that knowledge. As yet little light has been shed on differences in recontextualization. Constellation analysis offers a way of analyzing how a set of ideas is structured one way in research, differently in a curriculum, and differently again when taught and learned in classroom practice. Comparative analysis could show that some constellations are more amenable to restructuring than others, providing insight into the nature and value of different recontextualizations. Analysis could also reveal when and how it is valuable for the pedagogic unfolding of a constellation to differ from the schematic constellation of its logic.

Constellation analysis may also be practically useful for educators. It offers a way of mapping out lesson plans and teaching designs for the content to be taught and learned. Constellation diagrams could help educators make the knowledge being taught more explicit to students by highlighting key ideas and relations among them. They could be used to map progress through the sequencing of content and make visible how different issues come together. They could also serve as a way for students to demonstrate their understanding. Comparing students' diagrams of, for example, an explanation of tides to the teacher's diagram could help make clear what has been learned and what nodes, links and clusters need revisiting. In this way, constellation analysis offers a means of connecting studies of knowledge and studies of student conceptions, the dominant preoccupation in science education research.

Another area for future development is exploring different kinds of relations among ideas. Links may take many forms. One can draw here on other LCT concepts to examine their attributes. For example, enacting the concept of *epistemological condensation* (specifically its 'translation device' for clausing, see Maton and Doran 2017) would show how different links – classifying, composing, causing, correlating, etc. – add meaning to constellations at different rates. Similarly, analysis of *charging* would show how different valuations of nodes and clusters suffuse constellations. The possibilities offered by such work are yet to be explored. This chapter was but a first step: the future may be written in the stars.

Acknowledgements

We wish to sincerely thank Claire Flanagan for creating Figure 3.1, Greg Rusznyak for creating Figure 3.2 (inspired by http://www.datasketch.es/may/code/nadieh/), and David Fergusson and Kylie Wynne for insights into science textbooks.

Notes

1 See MacDonald (1998) and data available at www.stellarium.org.
2 Rusznyak (2020) goes further by using the constellation of Orion to additionally illustrate the concepts of *semantic density* and *condensation*.
3 Though these concepts were first introduced using concepts from the Semantics dimension of LCT (Maton 2014: 148–70), they do not belong to any dimension. Constellation and cosmological analyses can be conducted with concepts from *any* dimension.
4 Exceptions include: Lambrinos (2020), which distinguishes relations among nodes in dance teaching by how much complexity they add; and Doran (2020), which explores relations in terms of rhetorical moves that show how values are constellated.
5 For a complementary view of relations among ideas from systemic functional linguistics, see Doran and Martin, Chapter 5 of this volume.
6 Aggregating may involve separate clusters or separate nodes. In this chapter, teaching about Earth's seasons involves several clusters of ideas that are built separately before being brought together. In other fields aggregating may involve a large number of individual nodes. For example, in History lessons the discussion of a period may involve aggregating a large number of facts (Maton 2015).
7 Both are also *epistemological constellations*, in which stances are formal definitions (such as concepts and empirical descriptions). For discussion of *axiological constellations*, in which stances are affective, aesthetic, ethical, moral or political, see Maton (2014: 148–70), Martin *et al.* (2010), Doran (2020), and Tilakaratna and Szenes (2020).
8 We used the same method on the same textbooks for both tides and seasons. We expand on the process for constructing 'schematic constellations' in a future publication.
9 We draw on a major study funded by the Australian Research Council (DP130100481).
10 The video (https://www.youtube.com/watch?v=QcbN9SVkqYU) is by the US public service broadcaster KQED; the excerpt is narrated by Ben Burress, staff astronomer at the Chabot Space and Science Center in Oakland, California.
11 As stated earlier, our pedagogic constellation diagrams show nodes and links *in comparison to the schematic constellations* because of our specific aims here. Constellation diagrams of the teaching as it unfolds would differ.

12 The two preceding lessons included mentions of Earth's tilt, orbit, rotation, and how sunlight heats the Earth. However, these ideas were nodes in other constellations: explaining 'day and night' and explaining different temperatures on Earth. In neither case was the content constellated into an explanation of *seasons*. This highlights that no content is locked into a specific constellation. Mentions of, say, 'tilt' or 'orbit' are not necessarily discussions of 'seasons'.

13 The video is available at: https://www.teachertube.com/videos/what-causes-seasons-on-earth-657. Maton and Howard (Chapter 4, this volume) examine the teacher's use of this video in detail, as an example of using multimedia in science teaching, explaining why she replaced its audio with her own commentary.

References

Adendorff, H. and Blackie, M. A. L. (2020) 'Decolonizing the science science: When good intentions are not enough', in C. Winberg, S. McKenna and K. Wilmot (eds) *Building Knowledge in Higher Education*, London: Routledge, 237–54.

Arena, P., Warnant, P., Burrows, K., Everygreen, M. J. and Lofts, G. (2009) *Core Science: Stage 4 Complete Course*, Milton: John Wiley and Sons.

Bernstein, B. (1990) *Class, Codes and Control, Volume IV: The Structuring of Pedagogic Discourse*, London: Routledge.

Bishop, S., Bass, G., Champion, N., Gregory, E., McKenna, E. and Walker, K. (2011) *Nelson iScience for the Australian Curriculum, Year* 7, South Melbourne: Nelson Cengage Learning.

diSessa, A. (1993) 'Toward an epistemology of physics', *Cognition and Instruction*, 10(2/3): 105–225.

Doran, Y. J. (2020) 'Cultivating values: Knower-building in the humanities', *Estudios de Lingüística Aplicada*, 37(70): 169–98.

Ellery, K. (2017) 'Conceptualising knowledge for access in the sciences', *Higher Education*, 74(5): 915–31

Georgiou, H., Maton, K. and Sharma, M. (2014) 'Recovering knowledge for science education research: Exploring the "Icarus effect" in student work', *Canadian Journal of Science, Mathematics, and Technology Education,* 14(3): 252–68.

Glenn, E. (2016) '*From clashing to matching: Examining the legitimation codes that underpin shifting views about climate change*', unpublished PhD thesis, University of Technology Sydney, Australia.

Lambrinos, E. (2020) '*Building ballerinas: Developing dance and dancers in ballet*', unpublished PhD thesis, University of Sydney, Australia.

Land, R., Cousin, G. and Meyer, J. H. F. (2005) 'Threshold concepts and troublesome knowledge (3): Implications for course design and evaluation', in C. Rust (Ed.) *Improving Student Learning Diversity and Inclusivity*, Oxford: OCSLD, 53–64.

MacDonald, J. (1998) *The Arctic Sky: Inuit Astronomy, Stare Lore, and Legend*, Ontario: Royal Ontario Museum.

Martin, J. R., Maton, K. and Matruglio, E. (2010) 'Historical cosmologies: Epistemology and axiology in Australian secondary school history discourse', *Revista Signos*, 43(74): 4330–463.

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

Maton, K. (2015) '*Legitimation Code Theory: Past, present, future*', Opening Address, *LCT1 – First International Legitimation Code Theory Conference,* Cape Town, South Africa, June.

Maton, K. and Doran, Y. J. (2017) ‘Condensation: A translation device for revealing complexity of knowledge practices in discourse, part 2 – clausing and sequencing’, *Onomázein Special Issue*, March: 77–110.

Meyer, J. and Land, R. (2003) ‘Threshold concepts and troublesome knowledge’, *ETL Project Occasional Report 4*, http://www.etl.tla.ed.ac.uk/docs/ETLreport4.pdf

Rickard, G. (2011) *Pearson Science 7: Student Book*, Frenchs Forest: Pearson Education.

Rose, D., McInnes, D. and Korner, H. (1992) *Scientific Literacy*, Sydney: Metropolitan East Disadvantaged Schools Program.

Rusznyak, L. (2020) ‘Supporting the academic success of students through making knowledge-building visible’, in C. Winberg, S. McKenna and K. Wilmot (eds) *Building Knowledge in Higher Education*, London: Routledge, 90–104.

Salwén, H. (2019) ‘Threshold concepts, obstacles or scientific dead ends?’, *Teaching in Higher Education*, DOI: 10.1080/13562517.2019.1632828

Stannard, P. and Williamson, K. (1995) *Science World 7*, South Yarra: Macmillan.

Tilakaratna, N. and Szenes, E. (2020) ‘(Un)critical reflection: Uncovering disciplinary values in social work and business reflective writing assignments’, in C. Winberg, S. McKenna and K. Wilmot (eds) *Building Knowledge in Higher Education*, London: Routledge, 105–25

Unsworth, L. (1997) ‘“Sound” explanations in school science: A functional linguistic perspective on effective apprenticing texts’, *Linguistics and Education*, 9(2): 199–226.

Zhang, J., Alford, D., McGowan, D. and Tilley, C. (2013) *Oxford Insight Science: Australian Curriculum for NSW, Stage 4, Year 7*, South Melbourne: Oxford University Press.