Chapter 1
A Multidisciplinary Perspective on Animation Design and Use in Science Education

Len Unsworth

1.1 Introduction

Animation is now pervasive in the practices of science and science education. Science research centres are employing science animators to explain discoveries at the frontiers of research (Anderson, 2013; Iwasa, 2014; Iwasa, 2015; Martin, 2011); animations are included in online editions of major science journals such as *Nature* (e.g. Sasihithlu, 2019) and *Developmental Cell* (e.g. Isabella & Horne-Badovinac, 2016) with more widespread and increased use anticipated as online journals become the norm and reader access to animated content improves (Grossman, Chevalier, & Kazi, 2016); and animation is also increasingly being deployed as a dimension of science research methodology (e.g. Nosch, Foppa, Tóth, & Joos, 2015; Tarshizi, Sturgul, Ibarra, & Taylor, 2015; Villa, Olsen, & Hansen, 2017). In science education, animations have been used as educational resources to support science teaching and learning for several decades (Smetana & Bell, 2012) and research interest in this topic seems to be on a growth trajectory. The number of articles mentioning animation in major science education journals in 2019 was double the number in 2010. In *Research in Science Education* the increase was from 9 to 24 and in the *International Journal of Science Education* from 20 to 40.

In the construction and communication of scientific understanding, animation has become a major resource within the meaning-making mode of the moving image (*kineikonic* mode (Burn, 2013)), alongside and complementary to the established meaning-making modes of language and image. Tytler, Prain, and Hubber (2018) draw on research by Latour (1986) and Gooding (2006) to argue that the relation

L. Unsworth (✉)
North Sydney Campus, Australian Catholic University, North Sydney, NSW, Australia
e-mail: len.unsworth@acu.edu.au

between theoretical scientific claims made in papers and their raw research data is not unitary but distributed across a sequence of representational re-description pathways. Hence, generating, promulgating and interpreting scientific knowledge and comprehending and deploying the specialized representational forms of the discourse of science are completely interconnected. Tytler et al. (2018) support the view that students need to be able to interpret and generate both the generic and the discipline-specific verbal and visual representational conventions of the scientific community if they are to become scientifically literate (Bazerman, 2009; Klein & Boscolo, 2016; Unsworth, 2001). Hence learning science and learning the specialized representational forms of the discourse of science are also completely interconnected. The use of animation in science education needs to be seen in this light.

Approaches to the induction of students into the multimodal disciplinary literacy practices of science have differed most noticeably in the extent to which they incorporate the development of students' explicit and systematic knowledge of the semiotics or meaning-making resources of language and image and the use as a pedagogic tool of a meta-language describing these resources. Arguably the most educationally influential delineation of the semiotics of the discourse of science has emerged from systemic functional linguistics (SFL) through research on language led by Halliday (Halliday & Martin, 1993), Martin (Martin, 2017; Martin & Veel, 1998) and Lemke (1990, 2004) and related systemic functional semiotic (SFS) research focusing more on images led by Kress (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Kress & Ogborn, 1998; Kress, Ogborn, & Martins, 1998; Kress & van Leeuwen, 2006), Bateman (2008), O'Halloran (2003) and more recently Doran (2019). Such accounts of the multimodal discourse of science have clearly informed approaches to integrating disciplinary literacy development in science pedagogy such as the Representation Construction Approach (RCA) (Hubber & Tytler, 2017; Hubber, Tytler, & Haslam, 2010; Prain & Tytler, 2012; Tytler et al., 2018; Tytler & Hubber, 2010; Tytler, Prain, Hubber, & Waldrip, 2013) and Primary Connections (Aubusson et al., 2019; Hackling & Prain, 2008), but without their taking up the explicit teaching of knowledge about language and image and the associated metalanguage. On the other hand, disciplinary literacy pedagogies closely associated with SFL and SFS have emphasized the role of knowledge about language and image and have incorporated the explicit development of students' knowledge of linguistic and visual semiotic metalanguage as a key resource in disciplinary literacy learning and teaching (Dreyfus, Humphrey, Mahboob, & Martin, 2015; Fang & Schleppegrell, 2010; O'Hallaron, Palincsar, & Schleppegrell, 2015; Polias, 2015; Rose & Martin, 2012; Schleppegrell, 2011, 2013). However, while a prodigious amount of research has accumulated on the use of animation in science education, little attention seems to have been given to the semiotics of animation either as a resource for informing pedagogy or as explicitly taught facilitative knowledge for enhancing animation interpretation and creation. Notwithstanding its expanding use in science education, animation has not yet been fully acknowledged as a significant dimension of the multimodal disciplinary literacy of science, which all students need to be able to both interpret and produce. Recent

publications on global developments in literacy research for science education do not mention animation (Tang & Danielsson, 2018), and from 2015 to 2019, animation appeared in the title of only three papers published in the *International Journal of Science Education* and did not appear in the titles of any papers published in *Research in Science Education* or *Research in Science Teaching*.

It is now widely accepted among science education researchers that learning science entails students being inducted into the practices of scientific knowledge generation, validation and communication and that the distinctive representational forms of science discourse are integral to these practices (Tytler et al., 2018). Animation now functions as a significant representational mode embedded in the epistemic processes of science enquiry. For effective student induction into this functioning of animation to occur, multidisciplinary perspectives on optimizing the use of animation in science education need to be brought to bear. From a semiotic perspective it is important to specify how the distinctive meaning-making resources of animation may be deployed in the construal of the different kinds of meanings involved in the scientific explication of phenomena. From the perspective of developing students' multimodal disciplinary literacy, we need to determine how students can develop competence and confidence in the critical interpretation and strategic creation of the specialized animated representations of discipline knowledge. From the viewpoint of managing day-to-day science pedagogy in the classroom, there are many issues including determining the suitability of animations and approaches for their use with students at different grade levels; the articulation of animation with other representational modes; incorporating animation into established pedagogic practices, and the practicalities of determining the means to enable students to create animations that are functional to their scientific inquiry and to the demonstration of their scientific knowledge. A further crucial perspective is the assessment of students' science learning, which is increasingly involving animation. The chapters in this volume highlight examples of innovative developments in research from these various perspectives. While several chapters align with the theoretical approaches of SFL and SFS, others have a more cognitive orientation. This reflects the current discrete complementarity of different research traditions, whose common interests being brought together here may encourage greater transdisciplinary intersection in future studies in this field. The chapters are organized into the four main parts of the book, each of which is previewed and briefly discussed in the following sections of this chapter.

1.2 An Educational Semiotics for Science Animation

The shift to viewing the development of students' literacy in science as essential to their induction into the epistemic processes of the discipline has coincided with greater attention to the multimodal and increasingly digital nature of the disciplinary literacy of science and with the burgeoning of social semiotic explications of the distinctive deployment of the resources of language and static images in science

discourse. The very limited attention to science animation from a semiotic perspective is advanced in the innovative research reported in Chaps. 2, 3 and 4 in this volume, all of which derive their distinctive contributions from the theoretical foundation of SFL and SFS. In this section the generative potential of these approaches for explicating how the affordances of animation construct and communicate scientific knowledge will be proposed. Firstly, we will briefly note the variety of scientific representational modes which have been described using SFS and outline the key features of the theoretical framework that produce this versatility. Then the new developments in research in science animation based on SFS in Chaps. 2, 3 and 4 will be introduced.

The range of representational modes in science for which SFS approaches have detailed the nature of their meaning making resources range from language to static images, to graphs, symbols and gestures (Doran, 2019; Halliday & Martin, 1993; Kress et al., 1998; Kress & van Leeuwen, 2006; Lemke, 1990; Martin & Veel, 1998; O'Halloran, 2003). Further work has importantly extended to the intermodal orchestration of these in paper and digital media texts and in teachers' shaping of scientific knowledge in the classroom (Danielsson, 2016; Kress et al., 2001; Lemke, 1998; Tang, Delgado, & Moje, 2014). This versatility of SFL and SFS approaches derives from the fundamental bases of the theory. The genesis of SFS theory was in Halliday's SFL account of language as social semiotic (Halliday, 1978; Halliday & Matthiessen, 2004). SFL posits the complete 'interconnectedness' of the linguistic and the social. According to SFL, the structures of language have evolved (and continue to evolve) as a result of the meaning-making functions they serve within the social system or culture in which they are used. But an important aspect of the impressively seminal nature of Halliday's work lies in his very early emphasizing that language is only one semiotic system among many, which might include forms of art such as painting, sculpture, music and dance and other modes of cultural behaviour such as modes of dress, structures of the family and so forth. All of these modes of meaning-making interrelate and their totality might be thought of as a way of defining a culture (Halliday & Hasan, 1985, p.4). This conceptualization of language as one of many different interrelated semiotic systems, and hence the assumption that the forms of all semiotic systems are related to the meaning-making functions they serve within social contexts, indicates the capacity of the theory underpinning SFL to be extended more broadly to SFS, applying to all semiotic modes and to the development of inter-semiotic theory.

According to SFS any communicative context can be described in terms of three main variables that are important in influencing the semiotic choices that are made. FIELD is concerned with the social activity, its content or topic; TENOR is the nature of the relationships among the people involved in the communication; and MODE is concerned with the channel (graphic/oral) and medium (the role of language in the situation - as constitutive of or ancillary to the activity) of communication, and the ways in which relative information value is conveyed. These three situational variables that operate in all communicative contexts: FIELD, TENOR and MODE are related to the corresponding three main categories of meaning-making functions, or metafunctions, of all semiotic systems – the ideational, interpersonal and textual

metafunctions. Ideational meanings construe FIELD i.e. entities, events or relationships and their properties; interpersonal meanings construe TENOR, enacting attitudinal stance and participation roles in social relationships; and the textual metafunction construes MODE, organizing meaning elements in the text as a whole and their relative emphases. While these three kinds of meaning are always made simultaneously in all instances of all semiotic modes such as language and image, the means by which they are realized differs. For example, in language, ideationally, the meaning of a particular activity of a specified field is typically realized by an action verb such as 'explode' (or its nominalized form 'explosion'), whereas in an image such a meaning would be conveyed by what Kress and van Leeuwen (2006) refer to as 'vectors' (action lines); interpersonally in language a direct interchange with an interactant is realized by choices in the mood system of statement, command or question and by the second person pronoun 'you', while in images direct engagement is realized by what Kress and van Leeuwen (2006) refer to a 'demand' image where the gaze of the participant in the image is directed straight at the viewer; textually in language information that is given or assumed is normally located at the beginning of the clause and what is new information is located at the end of the clause, whereas in images the kinds of emphases are realized by positioning at the left and right of some images with a grid layout and at the centre or periphery of images organized with what Kress and van Leeuwen (2006) refer to centre-margin layout. Of course, SFL and SFS accounts detail very comprehensively and systematically the extensive meaning potential within each of the ideational, interpersonal and textual metafunctions and also the various options for realizing these meanings in all modes such as language, image and gesture etc. The systems of options for meaning making (within the stratum of semantics) is mapped against the systems of options (available within the strata of grammar and phonology/graphology of language and the visual grammar and graphological options of images) for the realization of these meanings. This kind of mapping means that it is possible to specify how the various modes make particular meanings. However, as Tang (Chap. 4, this volume) points out the nature of this inter-stratal mapping is influenced by the material nature of the medium through which different modes realize meanings.

> For instance, the temporal characteristics of human sound both afford and constraint speech as a mode to make meanings in a sequential manner. On the other hand, the spatial characteristics of visual representations allow meanings to be made and interpreted simultaneously instead of in sequence, thus allowing a unique way of meaning making compared to speech (Chap. 4, this volume).

This kind of systemic theorizing and analysis facilitates understanding and discussion of the commonalities and complementarities of the meaning-making that is possible in different modes as well as how such modes may function collaboratively to construct meanings in multimodal texts. Hence it can also inform pedagogic agendas for the development of students' multimodal disciplinary literacy. As yet however, there has been very little such theorizing and analyses applied to science animations. The contributing authors to Part I of this volume provide pioneering work in this area.

The ideational, interpersonal and textual analyses of science animations from TED-ed animations, study.com and the online portal of *Explain Everything* provided by Yufei He in Chap. 2, include new frameworks for the analysis of ideational and textual meaning in animation. She notes that from an ideational perspective a key affordance of animation is the dynamic portrayal of change and innovatively extends previous classifications (Lowe, 2003; Ploetzner & Lowe, 2012, 2017) to present a very detailed network of options for different kinds of change that can be manifested in animations, which she developed with Theo van Leeuwen (He & van Leeuwen, 2019). In this network (Fig. 1.1) there are four types of changes: inclusion, movement, illumination and transformation. Movement can be displacing (e.g. the earth orbits around the sun) or non-displacing (e.g. the earth rotates around its own axis, i.e. without changing position). Displacing or non-displacing movements can also be either rotational or translational (linear) or a combination of those two. Illumination includes change of colour or change of brightness. Transformation involves an element changing its size (rescale) or changing its shape (reshape). Each of these four types of change can be instantaneous or gradual. If gradual, the speed of change can be constant or variable. If the speed is variable, it may be increasing or decreasing and if constant the speed could be located on a continuum from fast to slow. He also provides a network of the verbal, pictorial or abstract elements (geometric forms, mathematical symbols, cues – such as locational arrows or frames) that can occur either separately or in combinations in animations. And any kind of element can undergo any kind of change.

Such a detailed framework of meaning-making options enables very precise description of the nature of change depicted in animations, facilitating critical discussion of how apposite the depiction choices in particular animations are in relation to the concepts being represented. In relation to textual meaning He draws on previous work (Ploetzner & Lowe, 2012, 2017) to represent the organization of information flow in animations as a network of options (Fig. 1.2). In He's terms organization flow is either accumulating or predicting. If accumulating the information flow may be either concurrent or retrospective. When the flow is accumulating and concurrent, the changed elements in animations construing activity are presented on the same screen (for example, using a split screen to show the molecular change as a substance changes from solid to liquid). When the accumulation is retrospective, the changed elements are presented on different screens (for example, the molecular view of a substance changed into the gaseous state would be represented on a subsequent screen to that representing the substance as a solid or a liquid). If, on the other hand the information flow is predictive, information is not aggregated over successive screens but rather, the aggregated information is presented as a whole and the sequence of changes is highlighted by cues such a colour highlighting or superimposed frames or arrows.

The cognitive processing implications of such different forms of information flow have been discussed by Lowe and his colleagues (Lowe & Ploetzner, 2017). With respect to interpersonal meaning, He also discusses semiotic resources used in animations to construct viewer engagement and attitudinal meaning. In her corpus these are principally anthropomorphic devices as well as representing humans
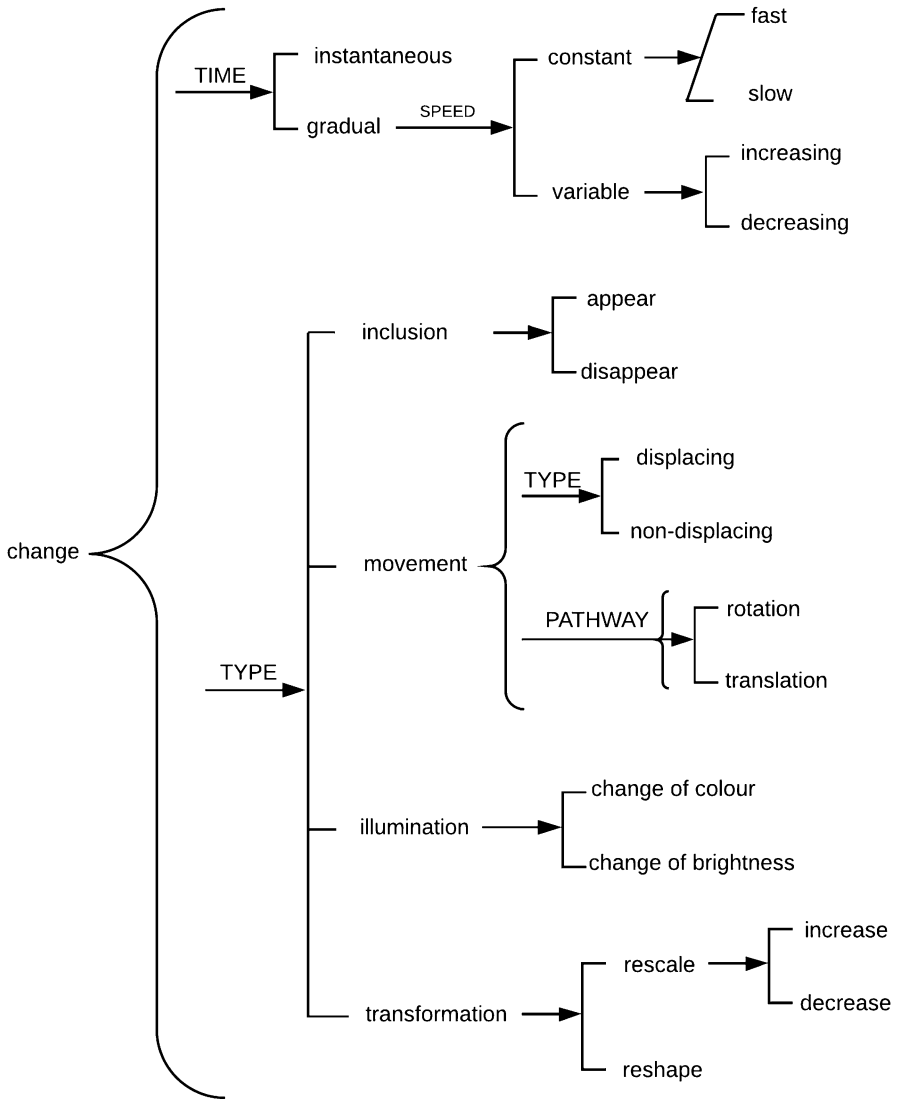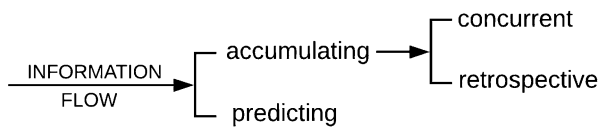
Fig. 1.1 System for change (adapted from He & van Leeuwen, 2019)

Fig. 1.2 The information flow system

depicted minimally and distortedly to humorous effect. The analysis framework demonstrated by He, encompassing the three dimensions of meaning proposed in SFS (ideational, interpersonal and textual) indicates the potential of this semiotic approach to productively complement cognitive orientated approaches and provide a highly comprehensive and integrated theoretical basis for the investigation, critical analysis and further development of the design features of animation, which currently receive so little attention in educational research.

Chapter 3 (Yu, Feng and Unsworth) focuses on the interpersonal metafunction, and particularly on the communication of attitudinal stance in a corpus of 67 ecology animations for children collected from Youtube. The analysis involved three phases. The first is based on the SFL appraisal framework (Martin & White, 2005). This framework includes three interacting dimensions: attitude, engagement, and graduation. Attitude encompasses: i) affect (un/happiness; dis/satisfaction; in/security), ii) judgments of individual's characteristics and capacities and the veracity and ethics of their behavior, and iii) appreciation of the significance and aesthetics of natural and artificial phenomena. Engagement addresses the sources of the evaluation expressed, the alignment of the author with these, and the extent to which the evaluations are portrayed as negotiable. Graduation deals with the amplification of meaning along a gradient of intensity of affect, judgment or appreciation (e.g., satisfied, indulged, satiated). The initial phase of the analysis identified all instances of attitude in the corpus and classified them according to the sub-categories of affect, judgment and appreciation. The second phase was based on a framework generated by the authors for the multimodal realization of attitude in animations (Fig. 1.3). The framework distinguishes attitude that is articulated through spoken or written language and attitude that is communicated through being embedded in the design of the animation characters or the animation's narrative structure. Attitudes can be explicitly articulated literally or by metaphorical language. They can also be articulated implicitly by describing an eliciting condition such as waste plastic causing the death of sea life or by describing remedying action such as banning the use of plastic straws in favour of paper straws. Attitude embedded in character design can be realized by narrative processes in the images (what the characters do as well as their facial expressions and gestures) and by conceptual processes of attribution and
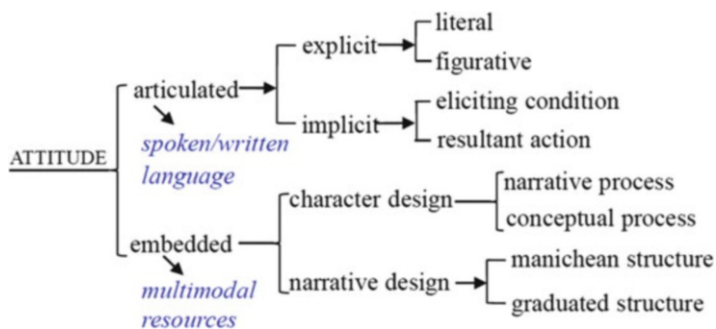

Fig. 1.3 The multimodal realisation of attitude

possession such as their clothing, colour and attributes such as symbols (e.g. green colour for environmental champions and black for agents of pollution). Attitude realized through narrative structure can involve opposing environmental hero characters with their anti-environmental villain counterparts or by showing gradual change in characters' behaviours as a result of experience of the negative impact of anti-environmental practices.

In the second phase of analysis, all instances of the various kinds of attitude in the corpus were cross classified with the means of their realization. These patterns of attitudinal meaning and their realization in the animations were then related to three different categories of pro-environmental value positions identified in the literature: egoistic (pro-environmental behaviours that benefit the individual such as saving on power costs); altruistic (environmental protection to benefit current and future generations of humans); and biospheric (environmental protection to benefit all forms of life on earth). While biospheric values were found to predominate, findings concerning the means of realizing the attitudinal meanings that construct this value position indicate that they are mainly realised by eliciting conditions and resultant remedying behaviour (often co-occurring) which mainly function to provide scientific explanations and recommend ways to solve the environmental problem concerned respectively. The chapter indicates the pedagogical value of the majority of online animations in the corpus in view of their balanced representation of knowledge and action-oriented aspects of environmental education. It also shows how this kind of semiotic analysis can contribute to an evidential basis for critical comparison of available animations of this kind.

In Chap. 4, Kok-Sing Tang and his colleagues use a semiotic approach to examine the multimodal affordances of a new form of animation made possible by virtual reality (VR) technology and discuss how these affordances facilitate student learning of molecular interactions. Immersive VR uses a head mounted display that enables the wearer to see a three-dimensional animation as if s/he were immersed within the three-dimensional space of the animation. Chemistry undergraduates were recruited to work in pairs to complete three activities using the immersive VR technology: (1) building the molecular structure of acetylcholine by moving several objects (representing pre-assembled functional groups of atoms) until they formed a bond when they were placed in close proximity to one another; (2) watching a scripted animated sequence that showed how acetylcholine is broken into two smaller molecules – acetate and choline; (3) exploring the structure of acetylcholinesterase to identify a particular gorge that leads into the active site where the reaction of acetylcholine takes place. The students could explore by walking around the enzyme, rotating it, and changing its size to the point where the students could zoom inside the enzyme. They could also change views according to different models of the enzyme, namely surface, mesh, ball-and-stick, cartoon and ribbon models. The chapter identifies five affordances of immersive VR 3D animation that are compared with flat screen 3D animation and the use of physical models: (1) viewing; (2) sequencing; (3) modelling; (4) scaling; (5) manipulating. Viewing the animation in immersive VR is not constrained by screen size or perspective – the animation can be viewed from any angle, as is the case for physical models. Sequencing is the

concatenation of images so that they dynamically represent a sequence. This affordance is common to immersive VR and flat screen 3D but the combination of sequencing with the Immersive VR affordance of viewing provided a new means of students' perceiving the represented activity. Modelling refers to the fact that the VR application was programmed to enable the display of different molecular models of acetylcholine and acetylcholinesterase, such as surface, mesh, ball-and-stick, cartoon and ribbon models. It is possible to switch from one model to another dynamically maintaining spatial correspondence of the different models. Scaling is the capacity to zoom in or zoom out, which is also possible with flat screen 3D but with the viewing affordance of immersive VR 3D and its high-level scaling, it is possible for the viewer to enter inside an object to view its constituents. Manipulating by moving or rotating animation elements is also possible with flat screen 3D but it is the combination with the viewing affordance of immersive VR 3D that enables the viewer/participant to engage in tactile manipulation while maintaining the three-dimensional spatial orientation of the visual object relative to his/her point of view. Immersive VR 3D animation combines the advantages of flat screen 3D and physical models. Its great advantage is that the viewing affordance can combine with each of the other affordances. The chapter clearly shows how this facilitated student learning in relation to the three learning activities they undertook. From the perspective of SFS, the viewing affordance concerns interpersonal meaning (what Kress and van Leeuwen call interactive meaning in reading images) – the nature of the relationship between the viewer and the represented participants in the animation, which changes according to the viewing angle and social distance between the viewer and the animation participants. Sequencing or the representation of activity refers to ideational meanings. It is textual meaning that is involved in the affordances of modelling and scaling. These deal with the organization of the represented information. Modelling uniquely has the capacity to organize the presentation of different models dynamically while maintaining spatial correspondence and scaling organizes the size of representations relative to the viewer. Manipulating appears to involve ideational and textual meaning as it seems to entail sequencing in enabling different positional arrangements of elements in the animation. In SFS terms then, immersive VR augments the semiotic resources of animation through enhanced affordances related to interpersonal and textual meaning.

1.3   Learning from Viewing Science Animations

The chapters in Part III of this volume highlight student learning from animations in the beginning and later years of primary school and in senior high school. As well as contributing to an understanding of the nature of the impact of active viewing of animations on student learning, the first two chapters draw attention to the importance of further research attention to the semiotic design of science animation. The third chapter emphasizes student perception of the value of learning from expert

animations relative to their own exploratory animation creation as part of a guided enquiry approach in their senior high school chemistry class.

In Chap. 5 Garry Falloon draws attention to the limited research on learning from science animation by children in the early years of school. He conducted two studies of five-year-old students learning about electric circuits from animated simulations in an elementary school in New Zealand. The research investigated the strategies and cognitive processes used by the children to build procedural knowledge (know how) and conceptual knowledge (know why) and the transfer of learning from their initial learning experiences with the simulations to application with different simulations as well as their transfer of leaning to undertaking practical tasks in building electric circuits. The results indicated that procedural knowledge was effectively learned from the simulations and transferred when using different simulations, but the transfer did not occur to the same extent in the students' application to using practical materials to build electric circuits. There was limited development and transfer of the students' conceptual knowledge. As well as emphasising the need for further research into the transfer of conceptual learning of young children from simulations to practical applications, the chapter also briefly notes the issue of animation design and the potential of some visual representations of concepts leading to misconceptions in students scientific understanding. The recommendations for critical review by teachers, increased trialling by app developers and improved app design, support the contributing role of semiotic analyses in complementing more cognitively oriented studies of science animation.

Chapter 6 deals with the impact of specially constructed animated versions of a multimodal science text on the learning of fifth grade low-skilled readers. The multidisciplinary team of Chilean researchers led by Max Montenegro first constructed a static multimodal text explaining energy transfer in an eco-system. They then produced two different animated versions of the text. One version scaffolded scientific concepts through animations that visually elaborated complex processes that were succinctly presented in condensed form in the verbal text. At the beginning of every page, the aural text was presented simultaneously with the animated images, but without the written text. Students were able to access the written text with a mouse click. In the second version of the animation the emphasis was on the scaffolding of academic language. In this version initially the written and aural text were presented simultaneously, and students were then able to click on unfamiliar vocabulary and logical conjunctions to access assistance in the form of simplified explanations or animations designed to support understanding of the verbal representation of the scientific processes. Three groups from a total of 84 students each experienced one of the three forms of the text: (1) non-animated; (2) scientific concepts scaffolded; (3) academic language scaffolded. Measures of scientific understanding, reading comprehension and vocabulary knowledge derived from the target text showed that both of the groups that experienced the different versions of the animated texts performed better on all three measures than the group that experienced the non-animated text, but there were no statistically significant differences in the results of the two groups who used the animated versions. It seems that the inclusion of aural text with the animations can boost the learning

performance of low-skilled readers with limited background knowledge of topics involving complex processes such and the transfer of energy in eco-systems.

In Chap. 7 Zeynep Yaseen discusses an intervention in senior high school chemistry in which student viewing and creation of animations of sub-microscopic representations of states of matter from solid to liquid to gas were incorporated into the well-known representation construction approach (RCA) to science pedagogy (Hubber & Tytler, 2017; Prain & Tytler, 2012; Tytler et al., 2013; Tytler et al., 2018). One class of year 11 students in Turkey working in pairs or groups of three used the *K-sketch* software program (http://www.k-sketch.org/) to create an animation of what they imagined could be seen with an impossibly powerful microscope looking into matter in the different states. The group-created animations were then shared and critiqued in a teacher guided class discussion as students reviewed and considered revision of their represented conceptualizations. Subsequently the students viewed animations created by experts using *K-Stretch* and other software and the students again reviewed and revised their conceptualizations. After the intervention the students and the teacher were interviewed about their opinions of the teaching/learning process using the animations. While post intervention assessment indicated substantial learning had occurred, the interviews indicated that very limited learning occurred during the students' animation creation and subsequent classroom discussion and critique. The animation construction did make the students' misconceptions explicit, but they perceived viewing the expert animations as most efficacious in developing their understanding. The students felt this viewing of expert animations was indispensable to their learning, although creating their own animations may have alerted them to attend closely to the conceptual representations in the expert versions. The study suggests that the pedagogic interface between students' representation construction using animation and their guided analysis and critical interpretation of expert or canonical animations warrants further investigation. As animation creation was a novel experience for these students, an additional implication of the study may be consideration of the extent to which students' familiarity and confidence in their knowledge and deployment of the options for constructing meaning with the resources of animation software may influence their capacity for both creation and critique of conceptual representation in science animations.

1.4   Learning through Creating Science Animations

The three chapters in Part III all involve applications of the 'slowmation' approach to student animation creation introduced in Chap. 8. The three chapters also illustrate the transdisciplinary approach of the authors, who are all science education academics, in drawing on key semiotic principles included in the outline of SFS in Sect. 1.2. While there has been extensive uptake of the 'slowmation' approach, the increasingly accessible general animation software (such as K-Stretch, see Chap. 7), and the increasing recognition of animation in the conduct and

communication of scientific research (see Sect. 1.1) indicates the need for further research into the pedagogic use of science animation creation from the early years of schooling through to tertiary science education.

In Chap. 8 Garry Hoban draws attention to the essentially transdisciplinary nature of student generated digital media representations in science education that integrate skills in science, media, semiotics, computing and coding. In response to the need to improve the engagement and discipline knowledge of teacher education students in science and taking account of the critique of science education animations as providing information too quickly for effective learning from them, Hoban devised 'slowmation' (slow animation) - an approach to enabling students to generate stop-motion science animations paced slowly enough for them to explicate their detailed understanding of science concepts for novice audiences and without the need for sophisticated subject-specific software. This involves students making three-minute narrated stop-motion animations by using everyday materials, such as plasticine, cardboard, or paper, or existing plastic models that are digitally photographed as they are moved manually along with enhancements such as music or static images. Slowmation greatly simplifies the process of creating an animation enabling preservice teachers to: (i) make or use existing 2D or 3D models that may lie flat on a table or the floor; (ii) play the animation slowly at 2 frames per second requiring 10 times fewer photos than normal animation; and (iii) use widely available technology such as a digital still camera, a tripod, and free movie-making computer software. The take up of slowmation in science teaching and research studies on its use are now very extensive indeed. Further development of the approach to student-generated digital media representations involves blended media whereby students create a 'media collage' using media products such as slowmation, still images including downloads from Google Images, personally made video and/or video downloaded from Youtube, enabling students to mix and match media for particular purposes (Hoban, Nielsen & Shepherd 2016). Hoban emphasizes the importance of students being aware of the affordances of each digital mode in selecting the most appropriate to suit the purpose of the explanation, underlining the fundamental transdisciplinary competencies required for student-generated multimodal digital representation in science.

In Chap. 9 Peta White, Russell Tytler and Wendy Nielsen describe a study in which 17 year 11 biology students worked in pairs or groups of three to produce a slowmation explanation for their peers of a topic in the senior high school biology curriculum. In a two-hour period, they were provided with iPads loaded with the app 'Stop Motion', a range of construction materials including papers of several weights and colours, scissors, pipe cleaners, paddle pop sticks, toothpicks, modelling clay, thumb tacks, glue, sticky tape, pins, coloured markers, and a collection of biology textbooks and other reference materials. The study investigated the processes of collaborative reasoning that occurred for one group of two students during the different phases of the construction of the slowmation animation and the learning opportunities that were opened up by the translation from text and static image to slowmation production. Through their re-representation of the intricacies of the digestive process (chemical and physical digestion with enzyme and organ detail)

the students needed to confront the fact that different representational modes support different, and necessarily partial, understandings of phenomena. Such constraints are shown to be productive of enhanced student understanding of phenomena as they engage in relating the different modes. The students' reasoning about biological phenomena initiated through this cross-modal translation was revealed through analyses of video and audio records of the two-hour period during which the group worked on creating the slowmation, storyboard sketches used as planning tools, the final slowmation product, and artefacts generated during construction. The analyses illustrate how creation of the visual-temporal rendition in the animation offers a productive constraint on the students' visualisation of the part-whole relations and temporal sequencing of the digestive processes. In cross-modal translation students are obliged to attend to the semiotic means by which biological processes and part-whole relations are represented in language (i.e through nominalisations such as 'secretion' or 'mucus failure' and classifer/noun structures such as 'abdominal cavity' or 'parietal enzymes'), and they also need to be aware of the visual semiotic means by which such processes and relations are represented in both static and dynamic images. This raises the issue of whether the pedagogic effectiveness and potential of cross-mode translation may be impacted by the extent of student familiarity with these semiotic resources and in addition, whether a metalanguage for the description of such resources being shared by teachers and students might further facilitate the productive reasoning among students and in teacher-student discussion of cross-mode translation.

In Chap. 10 Wendy Nielsen and her colleagues adopted the blended media approach discussed in Chap. 8 to generate a digital media creation task for pre-service primary teacher education students as part of their assessment in a course on primary science curriculum and pedagogy. The digital explanation creation task required students to explain how a car demister works using multimodal resources in a manner accessible to a primary school student in year six. The task was intended to assess the students' knowledge of the subject matter, their knowledge and use of multimodal resources and the appropriateness of their artefacts for students in the final year of primary school. The student artefacts were assessed using a rubric based on the SFS contextual variables of field (representing science); tenor (attention to audience); and mode (media choices). While almost all students had very limited prior knowledge about how electric circuits functioned in car demisters, the analysis of the student artefacts (and interview analyses) indicated a wide range of demonstrated knowledge in the digital explanations as illustrated in a detailed analyses of two explanations illustrating the highest and lowest levels of knowledge. This range of field knowledge broadly correlated with the appropriateness and of their choices of media and the suitability of the digital explanations for the intended audience. An implication of the work presented in this chapter is the potential of student-generated digital media explanations as an engaging pedagogic device to integrate the development of teacher education students' disciplinary knowledge and digital multimodal discourse of science as part of their preparation of pedagogic resources appropriate for their future primary school pupils.

1.5 Using Animation in Assessing Students' Science Learning

The incorporation of animation into large scale government conducted tests of students' science learning as well as in very widely administered international tests has drawn attention to practical challenges in the production and implementation of such tests as well as issues of concurrent validity related to students' experience of this mode of assessment and construct validity related to the design of the animations and the assessment items based on them. The chapters in Part IV of this volume include discussion of such challenges and specific proposals for addressing them.

In Chap. 11 Jennifer English describes the use of animation in the online science assessments that have been undertaken by all students in government schools in years six, eight and ten in the State of New South Wales (NSW) in Australia since 2014. This science assessment program is known as the *Validation of Assessment for Learning and Individual Development* (VALID) program. The online assessments include static and animated stimulus material and the assessment items include those requiring extended written responses as well as well as multiple choice, matching and drag and drop responses. The animations are of two main types: (1) those that are display and play similar to a video; and (2) interactive animations that allow students to select variables which produce variance in the array of graphic entities and/or activities. Interactive animations are primarily used to assess procedural knowledge concerning the nature and conduct of science investigations. Descriptions and illustrations from the different types of animations and assessment items in VALID are included along with explanations of the procedures employed by the NSW Government Department of Education personnel to establish the validity and reliability of each assessment item. As well as outlining the theoretical bases of the development of the assessments, the chapter also points out a range of practical considerations that need to be taken into account in the use of animation in this State-wide online science assessment. These include the costs of bespoke animations created specifically for the assessment program and of copyright costs if existing published animations are used. Open access online animations need to be checked for scientific accuracy and regardless of the source, the file size of animations needs to be carefully monitored as the online assessment needs to be accessible throughout the large State of NSW and in some regional, rural and remote areas where internet connections may be unreliable and admit only limited bandwidth. A further challenge is the sourcing of animations on curriculum specific topics that are suitable for students at the three different grade levels. Nevertheless, the successful development and implementation of this government funded assessment program since 2014, has substantially advanced understanding of issues involved in the use of animation for assessment and affords great opportunities for further such research and development.

In Chap. 12 Ya-Chun Chen, Zuway-R Hong, and Huann-shyang Lin describe a study that compared the performance of students who completed science assessment items in the Program for International Student Assessment (PISA) 2015 Field Trial

test in Taiwan in three different formats: (1) static stimuli and paper-based assessment (PBA); (2) static stimuli and computer-based assessment (CBA) and stimuli including animation and simulation with computer-based assessment (ACBA). On the overall performance PBA did better than CBA, which did better than ACBA. Detailed further analyses considering format type in relation to high, mid and low-level achievers showed the same pattern for high achievers but no format effect for mid and low-level achievers. Relatively lower performance by the ACBA group was sustained when separate analyses addressed explaining science concepts; designing and evaluating science investigations; and interpreting data and evidence. The format effect seems quite clear, although it cannot be absolutely confirmed since there was no pre-test of science competency. The researchers collected data on the use and disposition of participants in relation to Information and Communication Technology (ICT). They found a weak but significant effect on student performance for participants' ICT interest and perceived competence and autonomy. The relatively low performance by the ACBA group may have been due to experience in responding to animations as stimuli in science assessments, but it may also be related to the design of the animations and a mismatch between animation mode of the stimuli and the verbal response mode of the assessment items, albeit in a computer-based format.

In Chap. 13 Ric Lowe and Jean-Michel Boucheix take up the matters of animation design and response modes to address issues of validity in assessment of science learning using animation. They note the advantage of animation in being able to provide a veridical presentation of spatiotemporal relations (i.e. processes and procedures), particularly in representing complex and often simultaneous processes, such as those involved in the operation of electric motors. Animation can faithfully represent such dynamic content with a high degree of realism despite the component entities being represented in an abstracted manner. Because of the inherent linear sequential nature of language being able to devise an adequate verbal characterization of the dynamics of these kinds of complex and interdependent sets of processes is extremely challenging exercise, even for a domain expert. Hence the validity issue is that when dynamic processes of this kind are represented using animation, the assessment of their comprehension by students is almost invariably through some form of verbal response perhaps in conjunction with static image representation(s). The challenge then, is to devise student response alternatives that avoid the need to re-frame understandings into the linear-sequential format required for verbally based assessment approaches. Several experiments seeking solutions are described. While those involving the creation, completion or interpretive annotation of static images partially address the issue, it is the presentation of animated response alternatives from which students select the correct version or choose from true/false options that seem to most closely align the representation modes of the stimulus and the assessment item response. While the authors do not claim that their experimental materials could be readily directly applied in the assessment of science learning, they describe a range of novel non-verbal measurement tools that could provide a basis for more valid ways of assessing learning from animation. This poses a very realistic

applied research and development agenda for educational assessment authorities and science animation developers.

1.6   Concluding Remarks

The studies featured in these chapters emphasize the growing importance of animation in many contexts of science education reflecting the increasing significance of animation in scientific investigation and communication. They highlight the inherent transdisciplinary nature of science animation and point to the value of bringing together cognitive, social semiotic, educational technology and pedagogic perspectives in addressing educational challenges of inducting students into this vital dimension of the disciplinary discourse of science and science education. As well as contributing to an improved understanding of current approaches to the use of animation in science education, the studies herein attest to the growing international crossing of disciplinary borders in science education research, which it is hoped will be a catalyst to further transdisciplinary initiatives enhancing learning in science through the pedagogic infusion of the evolving development of animation and associated forms of digital multimodal representation in scientific discourse.

References

Anderson, Q. (2013). Column: Animated science. *Nature, 502*(7470), 259–260. https://doi.org/10.1038/nj7470-259a

Aubusson, P., Skamp, K., Burke, P., Pressick-Kilborn, K., Ng, W., Palmer, T., et al. (2019). *Primary connections: Linking science with literacy stage 6 research evaluation final report.* Sydney, Australia: University of Technology Sydney.

Bateman, J. (2008). *Multimodality and genre: A foundation for analysis.* London: Palgrave Macmillan.

Bazerman, C. (2009). Genre and cognitive development: Beyond writing to learn. In C. Bazerman, A. Bonini, & D. Figueiredo (Eds.), *Genre in a changing world. Perspectives on writing* (pp. 279–294). Fort Collins, CO: The WAC Clearinghouse.

Burn, A. (2013). The Kineikonic mode: Towards a multimodal approach to moving image media. In C. Jewitt (Ed.), *The Routledge handbook of multimodal analysis.* London: Routledge.

Danielsson, K. (2016). Modes and meaning in the classroom–the role of different semiotic resources to convey meaning in science classrooms. *Linguistics and Education, 35*, 88–99.

Doran, Y. (2019). Building knowledge through images in physics. *Visual Communication, 18*(2), 251–277.

Dreyfus, S. J., Humphrey, S., Mahboob, A., & Martin, J. R. (2015). *Genre pedagogy in higher education: The SLATE project.* New York: Palgrave Macmillan.

Fang, Z., & Schleppegrell, M. (2010). Disciplinary literacies across content areas: Supporting secondary reading through functional language analysis. *Journal of Adolescent and Adult Literacy, 53*(7), 587–597.

Gooding, D. (2006). From phenomenology to field theory: Faraday's visual reasoning. *Perspectives on Science, 14*(1), 40–65.

Grossman, T., Chevalier, F., & Kazi, R. H. (2016). Bringing research articles to life with animated figures. *Interactions, 23*(4), 52–57.

Hackling, M. W., & Prain, V. (2008). *Impact of primary connections on students' science processes, literacies of science and attitudes towards science*. Canberra, Australia: Australian Academy of Science.

Halliday, M. A. K. (1978). *Language as a social semiotic: The social interpretation of language and meaning*. London: Edward Arnold.

Halliday, M. A. K., & Hasan, R. (1985). *Language, context and text: Aspects of language in a social-semiotic perspective*. Geelong, Australia: Deakin University Press.

Halliday, M. A. K., & Martin, J. R. (Eds.). (1993). *Writing science: Literacy and discursive power*. London: Falmer Press.

Halliday, M. A. K., & Matthiessen, C. (2004). *An introduction to functional grammar* (4th ed.). London: Arnold.

He, Y., & van Leeuwen, T. (2019). Animation and the remediation of school physics–a social semiotic approach. *Social Semiotics*, 1–20.

Hoban, G., Nielsen, W., & Shepherd, A. (Eds.). (2016). *Student-generated digital media in science education: Leaning, explaining and communicating science*. London, England: Routledge.

Hubber, P., & Tytler, R. (2017). Enacting a representation construction approach to teaching and learning astronomy. In D. Treagust, R. Duit, & H. Fischer (Eds.), *Multiple representations in physics education* (pp. 139–161). Cham, Switzerland: Springer.

Hubber, P., Tytler, R., & Haslam, F. (2010). Teaching and learning about force with a representational focus: Pedagogy and teacher change. *Research in Science Education, 40*(1), 5–28.

Isabella, A. J., & Horne-Badovinac, S. (2016). Rab10-mediated secretion synergizes with tissue movement to build a polarized basement membrane architecture for organ morphogenesis. *Developmental Cell, 38*(1), 47–60.

Iwasa, J. (2014). Crafting a career in molecular animation. *Molecular Biology of the Cell, 25*(19), 2891–2893.

Iwasa, J. (2015). Bringing macromolecular machinery to life using 3D animation. *Current Opinion in Structural Biology, 31*, 84–88.

Klein, P. D., & Boscolo, P. (2016). Trends in research on writing as a learning activity. *Journal of Writing Research, 7*(3), 311–350.

Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning: Rhetorics of the science classroom*. London: Continuum.

Kress, G., & Ogborn, J. (1998). Modes of representation and local epistemologies: The presentation of science in education. *SISC Working Papers, 2*, 2–22.

Kress, G., Ogborn, J., & Martins, I. (1998). A satellite view of language: Some lessons from science classrooms. *Language Awareness, 7*(2–3), 69–89.

Kress, G., & van Leeuwen, T. (2006). *Reading images: The grammar of visual design* (2nd ed.). London: Routledge.

Latour, B. (1986). Visualization and cognition. *Knowledge and Society, 6*(6), 1–40.

Lemke, J. (1990). *Talking science: Language, learning and values*. Norwood, NJ: Ablex.

Lemke, J. (1998). Multiplying meaning: Visual and verbal semiotics in scientific text. In J. R. Martin & R. Veel (Eds.), *Reading science: Critical and functional perspectives on discourses of science* (pp. 87–113). London: Routledge.

Lemke, J. (2004). The literacies of science. In E. W. Saul (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 33–47). Newark, DE: International Reading Association.

Lowe, R., & Ploetzner, R. (2017). *Learning from dynamic visualization*. Cham, Switzerland: Springer.

Lowe, R. K. (2003). Animation and learning: Selective processing of information in dynamic graphics. *Learning and Instruction, 13*(2), 157–176.

Martin, C. (2011). Drew Berry. *The Lancet, 377*(9769), 895.

Martin, J. R. (2017). Revisiting field: Specialized knowledge in secondary school science and humanities discourse. *Onomazein*, 111–148.

Martin, J. R., & Veel, R. (Eds.). (1998). *Reading science: Critical and functional perspectives on discourses of science*. London: Routledge.

Martin, J. R., & White, P. (2005). *The language of evaluation: Appraisal in English*. London/New York: Palgrave/Macmillan.

Nosch, D. S., Foppa, C., Tóth, M., & Joos, R. E. (2015). Blink animation software to improve blinking and dry eye symptoms. *Optometry and Vision Science, 92*(9), e310–e315.

O'Hallaron, C. L., Palincsar, A. S., & Schleppegrell, M. J. (2015). Reading science: Using systemic functional linguistics to support critical language awareness. *Linguistics and Education, 32*, 55–67.

O'Halloran, K. (2003). Intersemiosis in mathematics and science: Grammatical metaphor and semiotic metaphor. In A.-M. Simon-Vandenbergen, M. Taverniers, & L. Ravelli (Eds.), *Grammatical metaphor* (pp. 337–366). Amsterdam/Philadelphia: John Benjamins.

Ploetzner, R., & Lowe, R. (2012). A systematic characterisation of expository animations. *Computers in Human Behavior, 28*(3), 781–794.

Ploetzner, R., & Lowe, R. (2017). Looking across instead of Back and forth: How the simultaneous presentation of multiple animation episodes facilitates learning. In R. Lowe & R. Ploetzner (Eds.), *Learning from dynamic visualization* (pp. 51–68). Cham, Switzerland: Springer.

Polias, J. (2015). *Apprenticing students into science: Doing, talking, writing and drawing scientifically*. Stockholm: Hallgren and Fallgren.

Prain, V., & Tytler, R. (2012). Learning through constructing representations in science: A framework of representational construction affordances. *International Journal of Science Education, 34*(17), 2751–2773.

Rose, D., & Martin, J. R. (2012). *Learning to write, reading to learn: Genre, knowledge and pedagogy across the curriculum*. London: Equinox.

Sasihithlu, K. (2019). Heat transferred in a previously unknown way. *Nature, 576*(12th December), 216–217.

Schleppegrell, M. (2011). Supporting disciplinary learning through language analysis: Developing historical literacy. In F. Christie & K. Maton (Eds.), *Disciplinarity: Functional linguistic and sociological perspectives* (pp. 197–216). London: Bloomsbury.

Schleppegrell, M. (2013). The role of Metalanguage in supporting academic language development. *Language Learning, 63*(1), 153–170.

Smetana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education, 34*(9), 1337–1370. https://doi.org/10.1080/09500693.2011.605182

Tang, K.-S., & Danielsson, K. (2018). *Global developments in literacy research for science education*. Cham, Switzerland: Springer.

Tang, K. s., Delgado, C., & Moje, E. B. (2014). An integrative framework for the analysis of multiple and multimodal representations for meaning-making in science education. *Science Education, 98*(2), 305–326.

Tarshizi, E., Sturgul, J., Ibarra, V., & Taylor, D. (2015). Simulation and animation model to boost mining efficiency and enviro-friendly in multi-pit operations. *International Journal of Mining Science and Technology, 25*(4), 671–674.

Tytler, R., & Hubber, P. (2010). *A representation-intensive signature pedagogy for school science*. Paper presented at the Australian Association for Research in Education, Melbourne, Australia.

Tytler, R., Prain, V., & Hubber, P. (2018). Representation construction as a Core science disciplinary literacy. In K.-S. Tang & K. Danielsson (Eds.), *Global developments in literacy research for science education* (pp. 301–318). Cham, Switzerland: Springer.

Tytler, R., Prain, V., Hubber, P., & Waldrip, B. (2013). *Constructing representations to learn in science*. Dordrecht, The Netherlands: Springer.

Unsworth, L. (2001). *Teaching multiliteracies across the curriculum: Changing contexts of text and image in classroom practice*. Buckingham, UK: Open University Press.

Villa, C., Olsen, K., & Hansen, S. (2017). Virtual animation of victim-specific 3D models obtained from CT scans for forensic reconstructions: Living and dead subjects. *Forensic Science International, 278*, e27–e33.

Len Unsworth is Professor in English and Literacies Education and research director of educational semiotics in English and literacy pedagogy at the Institute for Learning Sciences and Teacher Education (ILSTE), at the Australian Catholic University in Sydney, Australia. Len's current research interests include systemic functional semiotic perspectives on multimodal and digital literacies in English and in curriculum area teaching and learning in primary and secondary schools.