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Analysing Multimodal Texts in Science—a Social Semiotic Perspective

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Abstract

Teaching and learning in science disciplines are dependent on multimodal communication. Earlier research implies that students may be challenged when trying to interpret and use different semiotic resources. There have been calls for extensive frameworks that enable analysis of multimodal texts in science education. In this study, we combine analytical tools deriving from social semiotics, including systemic functional linguistics (SFL), where the ideational, interpersonal, and textual metafunctions are central. In regard to other modes than writing—and to analyse how textual resources are combined—we build on aspects highlighted in research on multimodality. The aim of this study is to uncover how such a framework can provide researchers and teachers with insights into the ways in which various aspects of the content in multimodal texts are communicated through different semiotic resources. Furthermore, we aim to explore how different text resources interact and, finally, how the students, or authors of teaching resources, position themselves in relation to the subject. Data consist of one student text and one teaching resource text, both comprising drawn and written elements in combination with symbols. Our analyses of the student text suggest that the proposed framework can provide insights into students' content knowledge and, hence, how construction of multimodal texts may be a useful tool for formative assessment. When it comes to teaching resources, the framework may be a useful tool for teachers when choosing resources, particularly in relation to students' possibilities of meaning making when engaging with such texts, but also, as a basis for classroom discussions.

Keywords Multimodal analysis · Student-generated texts · Social semiotics · SFL · Biology education · Multimodality

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Introduction

Science involves abstract concepts, complex processes, and the study of phenomena which cannot always be experienced directly by our senses. Although language plays an important role in the communication of science, the scientific discourse is characterised by multimodality (Lemke, 1998; Kress et al., 2001), where students' meaning making depends on their interaction with several semiotic resources (Danielsson, 2016; Jakobson et al., 2018; Kress et al., 2001; Lemke, 1998). In science, abstract and complex phenomena are therefore often described and explained through visual representations. Research, however, indicates that students require more guidance when interpreting such representations (Eilam, 2013). Further, whereas such visual representations are central to students' meaning making in science, they are typically combined with other resources, such as writing and subject-specific symbols, in a *multimodal orchestration* (Kress et al., 2001). Thus, students need to integrate several modes in order to understand, learn, and communicate science. Seeing as the creation of multimodal texts has the potential to assist students in their meaning making of scientific concepts (Cheng et al., 2020; Tytler et al., 2018), analysis of such texts can provide insights into students' reasoning (cf. formative assessment, Black & Wiliam, 2009).

The quantity of visual representations in textbooks has increased in recent decades (Bezemer & Kress, 2008). In parallel, there has been a growing interest in analysing how visual representations are employed in such teaching resources (Danielsson & Selander, 2016, 2021; Dimopoulos et al., 2003; Unsworth, 2004, 2007). However, studies focusing on students' meaning making through image and writing in multimodal texts[1] are rare, especially in science (for one exception—see Kress et al., 2001). Previous frameworks for analysing student texts in science have mainly focused on: characteristics of drawings (Christidou et al., 2009; Tang et al., 2019), descriptive illustrations (Kress et al., 2001), abstraction levels (Park et al., 2020), and drawings and writing as a basis for assessment (e.g., Wilson & Bradbury, 2016).[2] Furthermore, a few studies have focused on the relation between image and writing in student texts (Kress et al., 2001) and teaching resources (Unsworth, 2004, 2007). Given this shortfall in research, there is a need to devise ways to analyse image and writing in multimodal teaching resources and students' texts, in order to gain an understanding of potential challenges presented by teaching resources and students' views of scientific processes. Our interest in texts that illustrate complex scientific processes arises from earlier research which indicates that complex phenomena, such as food webs and ecological systems, pose challenges to students' meaning making (Preston, 2018; Tytler et al., 2017). An example of this is in the use of arrows to designate various kinds of scientific processes (Preston, 2018), such as the difference between energy and the cycling of matter (Wennersten et al., 2020). In this study, we wish to contribute to filling this research gap by presenting a framework that can be applied to both (static) structures and complex processes. It combines analytical tools for text analysis, derived from social semiotics (Halliday, 1978; Halliday & Matthiessen, 2014), which

[1] In this study, "multimodal texts" refer to traditional, paper-based (printed or created by hand), or digital texts, and not, e.g., animations.

[2] In the referred studies, concepts such as image, drawing, diagram are not always used consistently. In line with Danielsson (2016), in this study "image" refers to the semiotic mode (e.g., Kress, 2010) and thus excludes written elements, while "drawing" corresponds to students' drawn representations, which can contain both writing and image.

builds on the close connection between form and function. The basis for the framework is systemic functional linguistics (SFL) and Halliday's systemic functional grammar (SFG) (Halliday & Matthiessen, 2014). Whilst originally developed for spoken and written language, SFG has been adapted to other modes, such as image (Kress & van Leeuwen, 2006) and combinations of modes (Martinec & Salway, 2005). Similar to Bergh Nestlog et al. (2020) and Danielsson (2016), we use SFG/SFL terminology for both writing and image, to facilitate comparisons between modes. We also employ terminology from Kress and van Leeuwen's (2006) visual grammar.

The aim of this article is to present a framework that can be used by researchers and teachers for analysing multimodal student texts and resources, to reveal their affordances and to shed light on (1) content expressed, (2) resources used for expressing the content, and (3) positioning made by the authors through their choices. When it comes to student texts, we relate these three aspects to *disciplinary literacy*, which is taken to be the ability to engage in "currently valued forms of disciplinary knowledge" (Moje, 2007:4)—in our case, the lexico-grammatical choices (Halliday & Martin, 1993) and visual representations (Tang et al., 2019) employed in the texts. Seeing as students and teachers may have limited knowledge about the potentials for meaning making related to different semiotic resources (Patron et al., 2017) and that such aspects of texts are seldom made explicit in classrooms (Siegel, 2012), the framework can be used in discussion with students to assist them in their understanding of the content and to support their disciplinary literacy (cf. Danielsson, 2010; Danielsson & Selander, 2021; Schleppegrell, 2013). To illustrate the analytical potential of the proposed framework, we have applied it to a student text in ecology and a teaching resource in chemistry.

Social Semiotics, Multimodality, and Systemic Functional Linguistics

A central premise of social semiotics is that form and function are intertwined—choices involving how content is expressed also affect what content is expressed, where the *sign* (a word, an image, a gesture) is considered to be the basic unit of meaning (Kress, 2010). From a social semiotic perspective, sign-making, meaning making, and learning are closely related. As Kress (2010:178) put it: "Semiotically speaking, sign-making is meaning-making and learning is a result of these processes." In line with this perspective, we define learning as "an increased capacity to use signs and engage meaningfully in different situations" (Selander, 2008:12). Furthermore, all social interaction is considered multimodal, simultaneously involving several semiotic resources in different resource systems, or *modes* (e.g., image, writing, and speech), where both modes and specific resources have different affordances, or potential for meaning making (Kress, 2010).

SFL, a central part of social semiotics, focuses on the function of language—more precisely, what language does and how it does it. From this perspective, each text, or utterance, displays three different meanings, simultaneously realised through different *metafunctions*: the *textual*, *ideational*, and *interpersonal* (Halliday & Matthiessen, 2014). The textual metafunction concerns organisation of the text and how meaning is presented to make it coherent. The ideational metafunction refers to our experiences of the world (i.e., content). Finally, the interpersonal metafunction concerns how we relate to the content and to others through interaction. Whereas the ideational metafunction has been the focus of a number of analyses of science texts (Jahic Pettersson et al., 2020; Martinec & Salway, 2005;

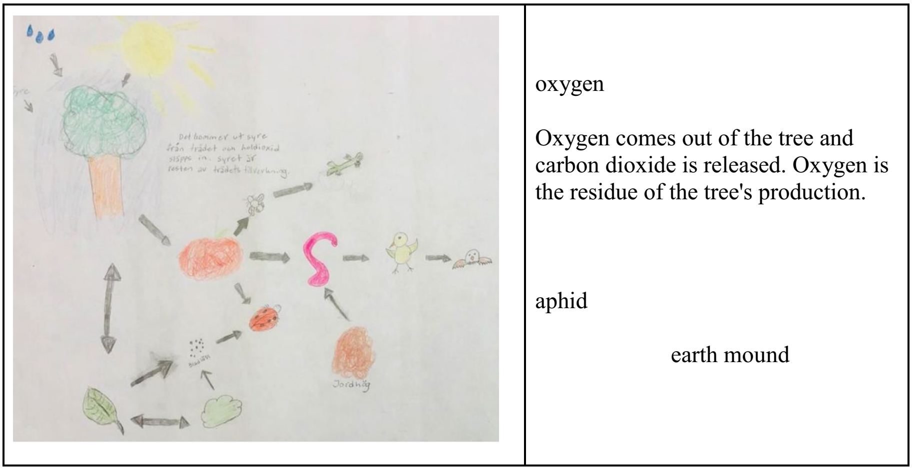


Fig. 1 Multimodal student text in ecology with translation from Swedish (for colour image, see online version)

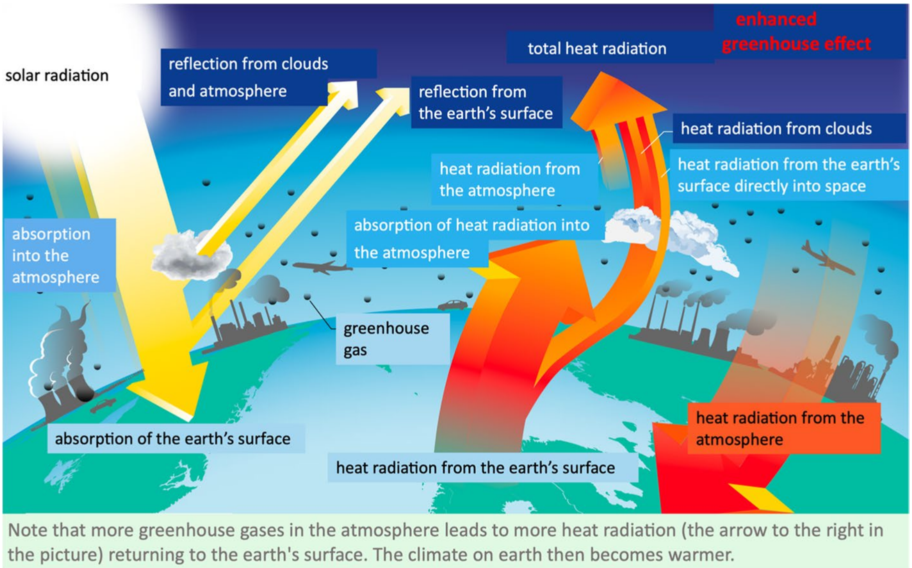


Fig. 2 Multimodal teaching resource in chemistry (Nationalencyklopedin (n.d.) (with translation from Swedish). Original image is available in Appendix 2, copyright Jens Klevje/NE. Reprinted with permission from: Olof Ollerstam/NE (for colour image, see online version)

Unsworth, 2007), Tang and colleagues (2019) investigated students' representations of concepts in physics and chemistry in relation to all three metafunctions, using terminology based on Lemke (1998).

Presentation and Application of the Framework

The presented framework is used to analyse the written and drawn elements of one paper-based student text (Fig. 1) and one digital teaching resource (Fig. 2). We also employ aspects of SFG which have previously been applied in the analysis of words and images (Christidou et al., 2009; Dimopoulos et al., 2003; Kress & van Leeuwen, 2006; Martinec & Salway, 2005), and more specifically for analysing visual representations in science (Tang et al., 2019). An overview of the analytical tools is provided in Table 1.

The paper-based student text was obtained from a mixed-gender Grade 7 (age 13–14 years) biology classroom.[3] At the end of a series of ecology lessons the students were given an assignment, consisting of a written instruction with images from their textbook illustrating a food web and an energy pyramid (Appendix 1). The students, working in groups of four, were asked to create texts to show how a food web functions. From their classwork, they had encountered ecological concepts, such as photosynthesis, food webs, and the role of decomposers. The texts produced by the students show many similarities (all are colourful with naturalistically drawn species). However, there were differences—with some texts focusing on the water cycle and others on the cycle of matter. The student text selected for analysis is regarded as being typical of the way students in the class presented ecological processes. In an upcoming article, we intend to present results from several texts. The teaching resource is a digital resource in chemistry aimed at students aged 13–15. As in the student text, it represents a complex process, namely the enhanced greenhouse effect.

In the following sections, the analytical framework is applied to the two texts, with each of the metafunctions outlined in Table 1 considered in turn.

Textual Metafunction (Te1 and Te2)

The analysis related to the textual metafunction is based on an overall analysis of the general text organisation (Te1), which considers the layout and choices of resources (e.g., image, writing, and symbols) and how they are combined in the text. In addition, a potential reading order (Danielsson & Selander, 2021) is determined to establish if the layout implies a certain sequence in which a reader might pay attention to the various text elements. For this overall analysis, we draw on Danielsson and Selander (2016, 2021). We also include those parts of the framework proposed by Tang and colleagues (2019) that refer to *spatial* aspects of texts, specifically the subcategories *relative size* and *scale* (Te2). Relative size considers whether depicted objects are of a similar size, and relative scale considers whether size, position, and spacing are realistic and proportional. Whereas Tang and colleagues (2019) link spatial aspects to presentational meaning (corresponding to the ideational metafunction), we have chosen to include them in the textual metafunction because we regard size, position, and proportion of elements as being related to the layout and composition of a text.

Student Text

Concerning overall structure, the text consists of two general text elements connected with arrows: (1) a tree, raindrops, sun, and air, placed in the upper left corner (representing

[3] This study is part of a larger project following the ethical principles stated by the Swedish Research Council (2017).

Table 1 Overview of the analytical tools based on SFL*

Textual metafunction	Ideational metafunction	Interpersonal metafunction
Textual metafunction 1 (Te1): organisation of text including choices of resources (image, writing, subject-specific symbols) Textual metafunction 2 (Te2): relative size and scale	Ideational metafunction 1 (Id1): transitivity analysis (processes, participants, and circumstances) of drawn/written Ideational metafunction 2 (Id2): narrative/conceptual function of drawn elements Ideational metafunction 3 (Id3): relationship drawn/written (redundant, complementing, elaboration, contrasting)	Interpersonal metafunction 1 (In1): positioning in relation to discipline and potential reader Interpersonal metafunction 2 (In2): speech roles (and equivalent for images) Interpersonal metafunction 3 (In3): formality Interpersonal metafunction 4 (In4): explicit/implicit values

*In the presentation of the framework, we refer to the abbreviations given in brackets in the table

photosynthesis) and (2) smaller separate images, connected with arrows (representing a food web). Through the drawn elements, both abiotic (sun and water) and biotic factors (related to organisms) are presented, and the organisms form a simple food web. The drawn elements are concrete and naturalistic in terms of form and colour and dominate the text; writing is only used for labels and for a caption. The placement of the two main text elements and the direction of the arrows implies two starting points for the reading order—either at the sun, in accordance with a Western reading order from left to right; or based on the direction of the arrows, at the leaf and bush. The potential reading order is then either from left to right or from the centre to the periphery of the drawing. The direction of the arrows implies that the bird of prey and lizard are end points in the food web. The various organisms are depicted disproportionately, with a worm depicted approximately as large as a bird of prey. Both are drawn smaller than the tree. Focus is thus not on the relative size of the organisms, but rather on the system as a whole.

Teaching Resource

This text contains two separate parts: a diagram and a caption. Regarding the overall structure, the text is dominated by three separated groups of arrows which connect the atmosphere and earth. On the whole, the diagram dominates the text. The writing consists of a heading, a caption, and labels providing information on radiation. By convention, the sun tends to be the starting point in a diagram such as this; thus, a potential reading order is from the top left to the bottom right, starting with the arrows representing solar radiation. The size and scale of the drawn elements are predominantly unrealistic and disproportionate, for example, gas particles and airplane wings are of similar size. The system—the earth's heat balance appears to be in focus.

Ideational Metafunction (Id1, Id2, and Id3)

Seeing as a principal goal in education is to communicate subject content, the ideational metafunction is central to the analytical framework. A transitivity analysis (Id1) (Halliday & Matthiessen, 2014) of written and drawn elements was performed, followed by a comparison of written and drawn elements (Kress & van Leeuwen, 2006; Tang et al., 2019). The relationship between the drawn and written elements in disciplinary texts is crucial.

However, seeing as both texts are mainly image-based and contain only a small amount of writing, these two analyses are somewhat limited in their extent.

Transitivity Analysis: Written Elements (Id1)

In the transitivity system, clauses are described as presenting *processes*, *participants*, and *circumstances* (Halliday & Matthiessen, 2014). Verbs can realise different process types: *material*, *mental*, *verbal*, and *relational*.[4,5] Material processes describe doings or happenings in the physical world ("eat"), whilst mental processes describe inner experiences, such as: thoughts, senses, and emotions ("to like"). Examples of verbal processes are "say" and "claim,", whereas relational processes relate participants to each other, for example, in terms of being ("is"). Participants are expressed by nominal groups, describing who participates in, or are affected by, the process ("the <u>bird</u> eats <u>worms</u>"). Circumstances are realised by adverbial groups or prepositional phrases, expressing, for example, how the process is related to space ("from the sun").

Student Text The caption related to the tree contains three clauses: (1) "Oxygen comes out of the tree," (2) "carbon dioxide is let in," and (3) "Oxygen is the remainder of the tree's production." These clauses contain two material ("comes out of," "is let in"[6]) and one relational process ("is"). The participants are mainly subject-specific: "oxygen", "carbon dioxide", and the noun phrase "the remainder of the tree's production," including a grammatical metaphor, "production." One circumstance relates to location: "from the tree." The labels consist of single, subject-specific words, both abstract ("oxygen") and concrete ("aphids").

Teaching Resource The written elements consist of a heading, labels, and a caption. Neither the heading nor the labels are expressed as clauses, and they contain no processes, e.g., the noun phrase "heat radiation from the earth's surface directly into space." In contrast, the caption consists of clauses containing one material ("returning") and two relational processes ("is," "will be"). Participants involved in these processes are subject-specific: "greenhouse gas," "climate," and "radiation." One mental process is realised ("notice"), addressing the reader. Participants in the labels realise several grammatical metaphors (e.g., "heat radiation"). Circumstances related to place are realised both in labels and the caption (e.g., "from the earth's surface") focusing on where something emanates. Altogether, these choices contribute to a dense language, typical of technical science texts (Halliday & Martin, 1993).

Transitivity Analysis: Drawn Elements (Id2)

Ecological processes are often visualised through arrows in chained, or cyclic, conversion processes, the former having clear starting and ending points with concrete (organisms) and abstract (photosynthesis) elements within the same image (Knain, 2015). The presence of arrows relates to Kress and van Leeuwen's (2006) categorisation of images with a

4 Halliday and Matthiessen (2014) also include existential and behavioural processes. In line with Danielsson (2016), we merge existential processes with relational and behavioural with material processes.

5 "Process" refers to linguistic choice (verb). When we refer to biological processes, we use expressions like "ecological process".

6 The students have used a material process (in passive voice) in Swedish: "*släpps in*" (is let in [passive]). In regard to the disciplinary content, this is incorrect, as carbon dioxide is actually released in the process.

narrative function (Id2), involving vectors, corresponding to material "action" processes (cf. "movement" in Tang et al., 2019). In contrast, images lacking vectors or arrows represent some kind of "being," corresponding to relational processes. Kress and van Leeuwen (2006) categorise such images as *conceptual*, either *classificational* (depicting relationships e.g., taxonomy) or *analytical* (such as part–whole structures).

Student Text The arrows in the two text elements mainly depict material processes—such as falling raindrops. Whilst this depiction performs a narrative function, at times the meaning is unclear. Where arrows point from one organism to another may imply either the cycling of matter ("who eats whom") or, in the case of the bush and the aphid, where an organism lives or obtains its nourishment. Participants related to the material processes are mainly concrete, naturally occurring entities: *a worm* is eaten by *a small bird*. Other arrows indicate relational processes, such as the one between "oxygen" and the blue area, or the double-headed arrow between the leaf and bush. Such arrows can be interpreted as indicating: a part–whole structure (the air *contains* oxygen), identification (this *is* oxygen; the leaf *is* part of the bush), or attribution (the bush *has* leaves). Circumstances relate to time, with the sun marking a starting point, whilst the lizard, ladybird, and bird of prey function as end points in a temporal sequence.

Teaching Resource The diagram contains several arrows of different sizes and colours, expressing material processes (absorption of solar or heat radiation) and having a narrative function. Participants in these processes are both concrete and abstract, for instance the earth's surface and the atmosphere, the latter depicted in two different hues of blue. The sizes of the arrows appear to represent different quantities of radiation. However, the use of straight and curved arrows may present challenges in interpretation—for instance, why is the solar radiation arrow straight, yet the heat radiation arrows curved? The drawn elements' features (e.g., their form) were analysed as attributes to participants, implying relational processes (such as the sun *is* yellow). Circumstances expressed in arrows relate to different consequences of radiation processes, such as absorption or reflection of radiation energy (light or heat) and the origin and end-point of these processes (place). Moreover, the relationship between some elements can be interpreted as circumstances, expressing where something emanates—heat radiation comes from the earth's surface, whilst light radiation emanates from the sun.

Relationship Between Drawn and Written Elements (Id3)

The relationship between drawn and written elements was explored in terms of *redundancy* (i.e., the same content in both modes), *extension* (the modes complement each other), *elaboration* (one mode specifies or exemplifies the other), and *contrast* (content in one mode contradicts the other) (cf. Danielsson & Selander, 2021; Martinec & Salway, 2005; Unsworth, 2007). In line with Martinec and Salway (2005), the level of generalisation of different resources was analysed through *exposition* and *exemplification*. Exposition implies that image and writing are at the same level of generality, e.g., both at a species level, whereas exemplification expresses a generality at different levels, e.g., a depiction at a species level with writing at a more general level (e.g., "plant"). Seeing as how an important aspect in disciplinary texts is the choice of mode in relation to affordance, we will also comment on how choices of text resources contribute to the presentation of the disciplinary content (cf. Danielsson & Selander, 2016, 2021).

Student Text Based on the analyses above, we conclude that the drawn elements are in extension to writing as they depict a larger number of processes, participants, and circumstances. The relationship between the written caption and the image depicting photosynthesis in the drawing is of interest. On the one hand, the written caption is in extension to the image since "carbon dioxide" is only given in writing. On the other hand, the image is in extension to the writing since it contains elements not mentioned in writing—for instance, there is no explanation of the role that the sun and water play in photosynthesis. As water uptake is challenging to depict (cf. affordance), a clarifying comment about the raindrop would be useful. In the food web, the drawn elements and written labels are in exposition, i.e., the same level of generality. The students appear to have chosen redundancy between image and writing mainly when the reader may find it challenging to interpret drawn elements such as aphids. However, it is left to the reader to interpret important aspects of the food web as a system, such as the meaning of the arrows. Overall, the writing focuses on photosynthesis, whereas the images realise important participants in photosynthesis (sun, water, and plant) and processes and participants in the food web.

Teaching Resource The drawn elements in the teaching resource realise more processes, participants, and circumstances than the written elements. Therefore, the image is in extension to the writing. Examples are the sources of greenhouse gas emissions (cars, airplanes, and industries) not mentioned in writing. The arrows can be challenging to interpret as they have different built-in meanings implied by their size, colour, and shape. An expert might infer that the yellow colour implies light whilst the red colour implies heat, though no guidance is given to the reader in this regard. The written and drawn elements at times constitute different levels of generality, which may aid a reader's interpretation of the diagram. For example, the label "greenhouse gas" is directed at one of the drawn gas bubbles, which results in exemplification. Yet, the type and degree of information provided by the labels vary—some labels clarify consequences ("absorption," "reflection"), others are aimed at sources ("from the clouds"). An expert in the field will fill in implicit information and might find the diagram self-explanatory, but the novice would likely need support interpreting it (cf. Danielsson & Selander, 2021).

Interpersonal Metafunction (In1, In2, In3, and In4)

The analysis concerning the interpersonal metafunction focuses on what choices can reveal about how the authors position themselves in relation to the content, discipline, and potential reader (In1). An analytical tool related to the interpersonal metafunction considers speech functions, such as statements, questions, offers, and commands (Halliday & Matthiessen, 2014:134 ff.) (In2). Through statements, we give information to others and also show authority. Questions and commands can be used to involve the reader, by speaking directly to her—a rhetorical strategy often used in textbooks. Students seeking to position themselves as authorities in the field are more likely to choose statements rather than questions or commands (Jeppsson et al., submitted). We also relate to Kress and van Leeuwen (2006) who discuss images in terms of offers or demands, where informative images in science, such as diagrams, are considered offers, again, as a way of displaying authority. In line with Danielsson and Selander (2016, 2021), we also look at explicit and implicit values, for example, expressions like "important," or images that present content in ways that can be interpreted as expressing values or norms (In4). Lexico-grammatical choices, such as disciplinary-specific terminology ("oxygen"), subject-specific symbols (O_2"), and other choices typical of scientific discourse, such as grammatical metaphors ("reproduction"), can also serve as a way of positioning oneself as an authority in the field. The same applies for visual resources, such as graphs, tables, and diagrams typically used within the discipline. Disciplinary choices in this regard have a degree of *formality* (In3) (Christidou et al., 2009; Tang et al., 2019)—the use of subject-specific language, symbols, and digits corresponds to high formality, and the use of everyday language and naturalistic images corresponds to lower formality (cf. modality in Kress & van Leeuwen, 2006).

Student Text

The written element related to photosynthesis consists of two statements presenting facts. Through this choice, the students position themselves as knowledgeable. The diagrams representing photosynthesis and a food web were analysed as offers (Kress & van Leeuwen, 2006). These diagrams may appear quite simple and ordinary, but since diagrams are common in the subject area, for instance in teaching resources, we consider the use of diagrams to be a way for the students to position themselves as knowledgeable. No explicit values are expressed, and the text appears to be distanced from the writer and reader, which also can be interpreted as a way to position oneself as authoritative. Other organisms than those shown in the assignment are depicted (see Appendix 1), which can be interpreted as a way to show expertise. Also, abiotic conditions necessary for an ecosystem are included (e.g., water), and in that sense, the students also position themselves as knowledgeable. Even though the reader is left to interpret important aspects, the text is to some extent adapted to a potential reader, with labels for depictions challenging to interpret, such as aphid and earth mound. Concerning formality, the students use subject-specific terminology including one nominalisation (production) and position themselves as knowledgeable. Some subject-specific symbols, such as arrows, are present, whereas others are absent, such as chemical formulas, leading to a lower degree of formality (Christidou et al., 2009). On the whole, our analysis indicates that these students in various ways position themselves as knowledgeable in the field.

Teaching Resource

The text is to some extent adapted to the potential reader; however, some labels, like the ones accompanying the arrows representing different types of radiation, may present challenges in interpretation. The use of statements, facts, and subject-specific language adds to the authoritative style, as to be expected in a teaching resource. One can also note the rhetorical strategy to involve the reader through commands such as: "Note that…" in the caption. When it comes to formality (Christidou et al., 2009), the text includes subject-specific terminology and some very prominent symbols (arrows) but does not contain subject-specific symbols such as chemical formulas, which results in a lower degree of formality. The image was analysed as an offer. Additionally, certain values (in this instance the negative impact which human activity has on the environment) are implied by the depicted industries, airplanes, and motorcars. Given the interplay between image and text and the underlying complexity of the subject matter, students will no doubt require significant guidance from their teacher when interpreting this diagram.

Conclusion and Implications

Previous frameworks for analysing texts in science education have mainly been developed for drawings (see e.g., Christidou et al., 2009) or, when based on SFL, have focused on ideational meaning (Danielsson, 2016; Jahic Pettersson et al. 2020; Martinec & Salway, 2005). The framework proposed in this study seeks to include all metafunctions in the analysis of the resources used in texts, and to consider the interaction between these resources. The framework was applied to a student text and a teaching resource, both of which present complex scientific processes. The analysis of the student text takes several modes into account and offers an assessment of students' content knowledge beyond that presented in written form, traditionally the dominant mode of assessment in school contexts (Kress & Selander, 2012). The analysis of the teaching resource highlights the challenges that teachers' may need to address in order to support their students' learning. Whilst our analysis was performed on examples of biology and chemistry texts, we propose that the framework can also be applied to other disciplines.

Student Text

Analyses based on the framework can provide insights into students' views of complex scientific processes and reveal shortfalls in their subject content knowledge and how to communicate subject content. Earlier research has emphasised that complex scientific phenomena, like food webs, are challenging for students to make meaning of (e.g., Preston, 2018). In our study, a lack of clarity in the student text indicates potential challenges concerning the subject content and confirms previous research that has highlighted the challenges that students' face when energy pathways are considered in combination with the cycle of matter (Wennersten et al., 2020). The students' use of arrows is at times inconsistent, which could indicate uncertainty regarding how to link the images in their drawing and/or the conventions for using arrows in this context. This also confirms earlier research that found that students faced challenges in the way arrows are used in science (Preston, 2018). The analyses linked to the interpersonal function revealed that the students position themselves as being quite knowledgeable in the area of ecology. This is evident in their use of subject-specific language in terms of lexico-grammatical choices and visual resources, through the overall structure (textual metafunction) and their choice to depict a simple food web in accordance with teaching and learning resources in the subject. In that sense, the text corresponds well to equivalent texts in educational resources. Yet, however much their text meets the task requirements (in terms of capturing the essential elements of a food web), one cannot, based on the text alone, conclude the extent of the students' understanding of the scientific content. This said, the analysis may very well constitute the basis for deliberate text discussions that can function as a support for teachers in this respect.

Teaching Resource

The analysis of the teaching resource highlighted some of the challenge's students may face when engaging with such texts. In this example, arrows have a central role, and their different shape, colour, and size imply a variety of functions and meanings that are not self-evident and thus need to be explicitly addressed. The combination of concrete and abstract participants (the earth's surface and the atmosphere) may also be challenging. Also, it is unclear if depicting the sky in different shades of blue is merely illustrative (as in a deepening in colour as you approach the boundary with space), or it is intended to carry a particular meaning which students need to discern in order to make sense of the diagram. Similarly, the use of grammatical metaphors, as in the label "heat radiation," is an example of the abstract and technical language of science (Halliday & Martin, 1993) that students may struggle to understand. Lastly, the analysis revealed the implicit values (cf. Danielsson & Selander, 2016, 2021) embedded in the drawn elements chosen to represent the impact of man on the environment, e.g. smoke from factory chimneys.

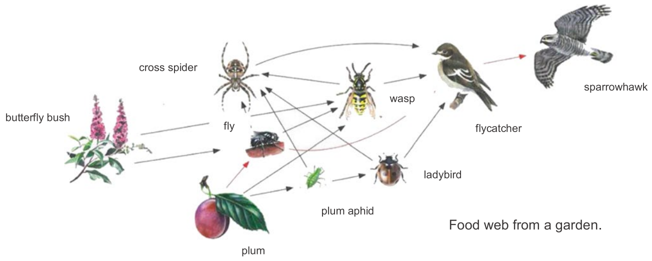
Discussing the content of texts and how it is expressed has been suggested as a tool for improving content learning (cf. Danielsson & Selander, 2016, 2021) and as a way of promoting students' disciplinary literacy (cf. Moje, 2007). In this instance, such a discussion with the students can include probing their choice of content and arrows to represent the relationship between different elements in a diagram. When it comes to the arrows, a discussion may also include a consideration of the conventions governing their use, particularly with respect to direction. Transitivity analysis of the student text revealed that the drawn elements are predominantly in extension to the writing, for instance when not mentioning the role of the sun and water in the written caption on photosynthesis. In discussions with students, this can be used as a point of departure for considering the affordance of image and writing, and the fact that abstract entities and complex biological processes are challenging to depict through images alone. For clarification purposes, then such images may need to be accompanied by written text. Potential questions are: "What can best be represented through an image and what requires clarification in words?" In relation to the interpersonal metafunction, teachers and students can discuss things like "When making this choice, will I appear knowledgeable in the field?" These discussions may emanate from the fact that form and function are intertwined, i.e., depending on your choice of text resources, you might position yourself in different ways.

When it comes to teaching resources, our framework may be a useful tool when choosing resources and can also function as a basis for classroom discussions. Depending on the teaching resource's features—such as symbols or technical language; or overarching aspects—such as the layout of text resources, or how different text resources relate to one another, the teacher might want to highlight different aspects of the text to emphasise potential functions and meanings. For texts similar to those analysed here, one important feature is the meaning of arrows and whether they are supposed to show direction or something else. For those familiar with the content, the interpretation might be obvious, but this might not be the case for the student (cf. Danielsson & Selander, 2016, 2021).

We believe that because of its multimodal approach, our framework can support the development of students' disciplinary literacy (Moje, 2007) whilst also serving as a tool for the development of students' and teachers' general multimodal literacy (cf. Danielsson & Selander, 2021; Patron et al., 2017). Whilst being knowledgeable in the field is central for all subject areas, to display your knowledge effectively you need to know *how and in what ways* to present it. Our analysis of a student text and teaching resource revealed several features of importance for the development of disciplinary literacy. These include the use of specific terminology including nominalisations, the different functions of arrows, how (relative) size of depictions may be central for the interpretation, and how the scientific processes presented in the texts are connected. Tang and colleagues (2019), found that key features of scientific phenomena are often excluded in students' drawings. The detailed analyses based on the proposed framework revealed that this was the case in the student text. The analyses also highlighted some important aspects of content implicit in the teaching resource. For example, it is not explained that greenhouse gases allow light to radiate from the earth into space but hinder heat from being emitted. This fact can only be gleaned from a correct interpretation of the arrows. Thus, the central information about the greenhouse effect is left implicit, namely that if the amount of greenhouse gases increases, an enhanced greenhouse effect can be observed.

The multimodal texts employed to communicate meaning in science are complex, and as such require an analytical framework which can discern all the important features of such texts. This is what we seek to be able to do with our proposed framework. However, its use in the classroom may be limited to the features of the text which the teacher wants to pay attention to. On the other hand, when it comes to formative assessment of student texts (such as the text considered here), we believe that it is important to take into account all resources presented—something which we believe our framework is equally able to do.

Appendix 1



Food web from a garden.

Show what is needed for the food web to function.

Show how the organisms in the food web get energy and matter.

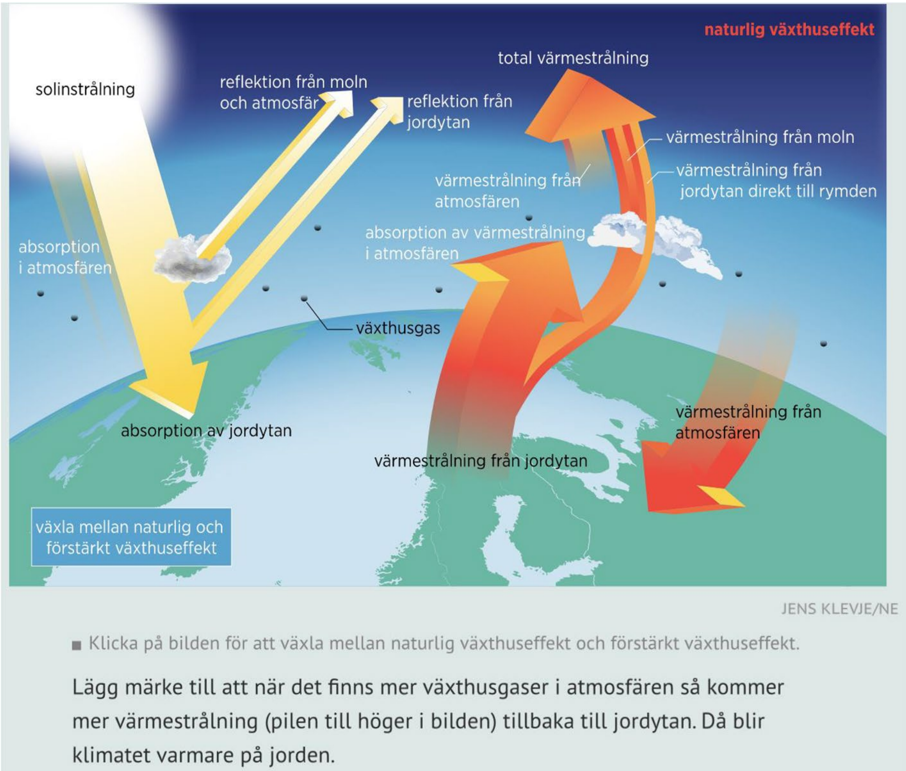
- how do animals get energy and matter?
- how do plants get energy and matter?

Show what is needed in the food web in order for energy and matter not to run out.

The energy pyramid shows that many plants are needed to support a small number of predators.

Assignment in ecology (translated from Swedish). (Illustration from the textbook Henriksson, TitaNO Biologi (2015) published by Gleerups Utbildning AB, copyright for the illustration: Oskar Jonsson). Reprinted with permission from: Oskar Jonsson (for colour image, see online version).

Appendix 2



Original multimodal teaching resource in Swedish (Nationalencyklopedin (n.d.), copyright Jens Klevje/NE). Reprinted with permission from: Olof Ollerstam/NE (for colour image, see online version).

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References

Bergh Nestlog, E., Danielsson, K., & Krogh, E. (2020). Multimodala elevtexter i geografiämnet (Multimodal student texts in the subject of geography). *HumaNetten, 44*, 11–44.

Bezemer, J., & Kress, G. (2008). Writing in multimodal texts. *Written Communication, 25*(2), 166–195.

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability, 21*(1), 5–31.

Cheng, M.M.W., Danielsson, K., & Lin, A.M.Y. (2020). Resolving puzzling phenomena by the simple particle model: Examining thematic patterns of multimodal learning and teaching. *Learning: Research and Practice, 6*(1). 70–87.

Christidou, V., Hatzinikita, V., & Dimitriou, A. (2009). Children's drawings about environmental phenomena: The use of visual codes. *The International Journal of Science in Society, 1*(1), 107–117.

Danielsson, K. (2010). Learning chemistry. Text use and text talk in a Finland-Swedish chemistry classroom. *IARTEM E-Journal, 3*(2), 1–28.

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.

Danielsson, K., & Selander, S. (2016). Reading multimodal texts for learning—A model for cultivating multimodal literacy. *Designs for Learning, 8*(1), 25–36.

Danielsson, K., & Selander, S. (2021). *Multimodal texts in disciplinary education*. Springer.

Dimopoulos, K., Koulaidis, V., & Sklaveniti, S. (2003). Towards an analysis of visual images in school science textbooks and press articles about science and technology. *Research in Science Education, 33*(2), 189–216.

Eilam, B. (2013). Possible constraints of visualization in biology: Challenges in learning with multiple representations. In C.-Y. Tsui & D. F. Treagust (Eds.), *Multiple representations in biological education* (pp. 55–73). Springer.

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

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

Halliday, M.A.K., & Matthiessen, C. (2014). *Halliday's introduction to functional grammar.* (4th ed.) Routledge.

Henriksson, A. (2015). *TitaNO biologi*. Gleerups Utbildning AB.

Jahic Pettersson, A., Danielsson, K., & Rundgren, C.-J. (2020). 'Traveling nutrients': How students use metaphorical language to describe digestion and nutritional uptake. *International Journal of Science Education, 42*(8), 1281–1301.

Jakobson, B., Danielsson, K., Axelsson, M., & Uddling, J. (2018). Measuring time. Multilingual elementary school students' meaning-making in physics. In K.-S. Tang, K. Danielsson (Eds.), *Global developments in literacy research for science education* (pp. 301–317). Springer.

Knain, E. (2015). *Scientific literacy for participation: A systemic functional approach to analysis of school science discourses*. Sense.

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

Kress, G. (2010). *Multimodality: A social semiotic approach to contemporary communication.* Routledge.

Kress, G., & Selander, S. (2012). Multimodal design, learning and cultures of recognition. *The Internet and Higher Education, 15*(4), 265–268.

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

Lemke, J. L. (1998). Multiplying meaning: Visual and verbal semiotics in scientific text. In J. Martin & R. Veel (Eds.), *Reading science* (pp. 87–113). Routledge.

Martinec, R., & Salway, A. (2005). A system for image-text relations in new (and old) media. *Visual Communication, 4*(3), 337–371.

Moje, E. (2007). Developing socially just subject-matter instruction: A review of the literature on disciplinary literacy teaching. *Review of Research in Education, 31*, 1–44.

Nationalencyklopedin (n.d.) *Växthuseffekt* (Greenhouse effect). Retrieved January 14, 2021, from https://laromedel.ne.se/material/reader/239/11017

Park, J., Chang, J., Tang, K.-S., Treagust, D. F., & Won, M. (2020). Sequential patterns of students' drawing in constructing scientific explanations: Focusing on the interplay among three levels of pictorial representation. *International Journal of Science Education, 42*(5), 677–702.

Patron, E., Wikman, S., Edfors, I., Johansson-Cederblad, B., & Linder, C. (2017). Teachers' reasoning: Classroom visual representational practices in the context of introductory chemical bonding. *Science Education, 101*(6), 887–906.

Preston, C. (2018). Food webs: Implications for instruction. *The American Biology Teacher, 80*(5), 331–338.

Schleppegrell, M. J. (2013). The role of metalanguage in supporting academic language development. *Language Learning, 63*(1), 153–170.
Selander, S. (2008). Designs for learning. *A Theoretical Perspective. Designs for Learning, 1*(1), 10–22.
Siegel, M. (2012). New times for multimodality? Confronting the accountability culture. *Journal of Adolescent and Adult Literacy, 55*(8), 671–682.
Swedish Research Council. (2017). *Good research practice.* Vetenskapsrådet. Retrieved from https://www.vr.se/english/analysis/reports/our-reports/2017-08-31-good-research-practice.html
Tang, K.-S., Won, M., & Treagust, D. (2019). Analytical framework for student-generated drawings. *International Journal of Science Education, 41*(16), 2296–2322.
Tytler, R., Haslam, F., White, P., & Peterson, S. (2017). Living things and environments. In K. Skamp & C. Preston (Eds.), *Teaching primary science constructively* (pp. 275–301). Cengage Learning.
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. 301–317). Springer.
Unsworth, L. (2004). Comparing school science explanations in books and computer-based formats: The role of images, image/text relations and hyperlinks. *International Journal of Instructional Media, 31*(3), 283–301.
Unsworth, L. (2007). Image/text relations and intersemiosis: Towards multimodal text description for multiliteracies education. *Proceedings of the 33rd international systemic functional congress*, 1165–1205.
Wennersten, L., Wanselin, H., Wikman, S., & Lindahl, M. (2020). Interpreting students' ideas on the availability of energy and matter in food webs. *Journal of Biological Education,* 1–21.
Wilson, R. E., & Bradbury, L. U. (2016). The pedagogical potential of drawing and writing in a primary science multimodal unit. *International Journal of Science Education, 38*(17), 2621–2641.