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Article

Primary Pupils' Multimodal Representations in Worksheets—Text Work in Science Education

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Abstract: Worksheets are common in science classrooms with an aim to support pupils' meaning-making, e.g., for guiding them in performing hands-on activities and documenting their experiences of such activities. Yet, there have been few systematic studies of pupils' disciplinary representations in worksheets. Drawing on systemic functional linguistics, we have analyzed fifth grade pupils' (age 10–11) multimodal texts in worksheets (n = 25) when they were working with shadow formation as part of their regular classroom activities. In the worksheets they were asked to first explain in writing why or why not a shadow was formed and then explain shadow formation through a drawing. At an overall level, we found that a majority of the pupils managed to express in writing why a shadow is formed, though it appeared to be more challenging for them to explain why a shadow is *not* formed. In their drawings, quite a few pupils managed to include several key aspects of shadow formation, at least when combining image with writing. For all tasks, the explanatory parts of the pupils' responses were often implicit. Based on our results, we suggest that pupils may benefit from teaching practices that integrate a parallel focus on form and content as a way to raise their awareness of, for instance, the affordances of different resources and how explanations can be structured. Such practices may support pupils to be able to consider and choose appropriate resources in their disciplinary texts.

Keywords: worksheets; shadow formation; systemic functional linguistics; meaning-making; multimodal texts

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1. Introduction

Becoming well informed and knowledgeable in science comprises mastering scientific terminology and concepts, scientific methods, interpreting empirical results, and being able to use an appropriate voice (e.g., regarding lexico-grammatical choices and functional visual representations) for communicating science content knowledge. Apart from a specialized language in terms of terminology and grammatical structures [1,2], the discourse of science is highly multimodal, with complex or abstract science phenomena being represented through a variety of modes [3]. Furthermore, science relies to a great extent on the development and use of models to describe and explain these phenomena [4]. In addition, each of these models and representations have their own specific potentials for meaning making [5]. While some aspects of a phenomenon will be emphasized through the choice of a specific representation, others will be de-emphasized. Hence, pupils need to crack the code regarding the discipline's ways to communicate [6] and make meaning of different models and representations of science phenomena. In this vein, learning science has been described as "learning to think with representations" [7] p. 88.

In worksheets used in science education, which is the focus of the present explorative study, pupils are often asked to use written language as well as images in their responses to questions posed in the worksheet. In addition, different resources, such as hands-on material, are supposed to support the pupils' meaning-making in relation to different science activities. The worksheets in the present study were used in conjunction with pupils' hands-on work on shadow formation. Historically, a substantial amount of research targeting pupils' understanding of light and shadow has been based upon cognitive developmental theories and other related pedagogical perspectives [8,9]. In addition, prior research on shadow formation has mainly been performed with preschool children [10,11]. In our study, on the other hand, the focus is not pupils' understanding of shadow formation as such. Instead, we investigate fifth grade pupils' explanations of shadow formation through multimodal texts in a regular classroom activity designed by their teacher.

In the following, we provide a brief overview of studies targeting research on pupils' science work related to hands-on science activities. The subsequent sections present our theoretical perspective, data and participants, and analytical methods, respectively. Thereafter, we present the results, which are finally discussed in terms of their implications for research and education.

1.1. Hands-On Science Work

It is often argued that science should let pupils experience different physical phenomena through their senses [12]. Hence, laboratory work and different kinds of hands-on activities are essential parts of school science, with the purpose of letting pupils interact with the physical world, for instance through observation and measurement, and to let them describe and explain the experienced phenomena. A vast number of studies has focused on such work, for instance regarding the effectiveness of laboratory work [13], and how pupils use different apparatus in laboratories [14]. In a study problematizing chemistry laboratory work within an undergraduate setting, Domin [15] put forward four frequent—although different—styles of laboratory instruction: expository, inquiry, discovery, and problem-based. Domin describes expository laboratory work as characterized by a well-defined topic, clear relations to students' prior experience, and clear instructions given in a manual, and he concludes that this is the most common and popular laboratory setup, both concerning different science disciplines and across different age groups. An alternative to such well-defined tasks with relatively detailed instructions is a setup building on free play where the pupils' interest guides the activity. One argument for such a setup is the fact that children's interest in science often arises in a spontaneous way through play, where it is possible to challenge and ask questions based on the children's own experiences and aspects of the activity that catch their interest and attention [16].

Since it may be challenging for pupils at different ages to use written language to express their experiences of a perceived phenomenon, drawings are often used as a means for teachers and researchers to capture young pupils' ideas [17–19]. This follows a popular instructional principle by Gardner [20] p. 93, who builds on Bruner's [21] idea of learning along three phases of thinking: concrete (action-based), pictorial (image-based), and abstract (language-based). The concrete phase involves hands-on manipulation of tangible objects most associated with play. The pictorial phase involves drawing or imaging the physical manipulation in visual forms. Finally, the abstract phase involves learning the conventionalized words and symbols that are associated with the phenomenon or concept. Gardner [20] suggests that the three phases of thinking, concrete, pictorial, and abstract, enable "children to transform experiences into knowledge: through action, through imagery and, eventually, through a range of symbol systems" (p. 93). Based on this idea, the pictorial phase using visual representations is supposed to function as an intermediator between pupils' hands-on work and development of written language.

Related to the idea of building on pupils' own experiences of hands-on work, Molander, Halldén, and Pedersen [22] investigated how different laboratory settings stimulate pupils' responses and how the students made use of their own common-sense ideas to explain an experiment. In their study, Molander and colleagues [22] divided 45 grade 4 pupils in a Swedish primary school into two groups to investigate how the pupils in the respective groups reasoned in connection to two different laboratory setups. One group followed a setup related to the pupils' own experiences with familiar laboratory material while the other group followed a setup that was a more traditional science setup including typical science laboratory material. The information given to both groups was that they would watch a demonstration and that they would then write down an explanation of what they had seen. The demonstration showed that air trapped in a vessel that is turned upside down, and then immersed in water, prevents water from filling the vessel. One of the findings from that study was that the different setups triggered different lines of reasoning. For instance, the group who saw familiar materials, such as kitchen tools, used everyday language, including words for kitchen tools, to explain what they had experienced. In contrast, the traditional science setup including typical science laboratory material seemed to encourage the pupils to use a more scientific language, including scientific terminology, when trying to explain what they had experienced [22].

Another strand of research with relevance to the present study concerns the use of notebooks. Here, the benefits of letting pupils use notebooks to document investigations and to formulate their ideas about them have been noticed, in particular when pupils use the notebooks to formulate their own ideas rather than transforming information given by the teacher into their notebooks [23]. Worksheets are usually prefabricated and structured around a number of assignments that the pupils are supposed to work with, while notebooks can be used according to the pupils' own interest, even if this is not always the case when pupils work with notebooks. For example, in a project performed in a number of secondary chemistry classrooms, the students mainly transformed the teacher's notes on the board into their notebooks [24].

1.2. Aim and Research Questions

The aim of this study was to explore how a worksheet is used in a regular classroom activity and how the worksheet functions as a resource for pupils' meaning-making of science content and for positioning themselves as knowledgeable in science after hands-on activities targeting shadow formation. Our study was guided by the following research question:

- What characterizes the pupils' answers in the worksheets in terms of content, structure of the texts, and how the pupils position themselves?

In the discussion section, our detailed analyses of the pupils' worksheets are connected to an overall description of the context in which the worksheet was used. The results are discussed concerning implications for science education.

2. Theory

Since science often deals with abstract phenomena or phenomena too small or too big to be perceived with our senses, the discourse of science depends on different means of representing the content, for instance through various types of diagrams combined with words [3,5]. Hence, meaning-making in science is highly multimodal. Additionally, the worksheets analyzed in the present study were multimodal, comprising writing and drawn images. Therefore, our theoretical perspective is social semiotics [25,26], which is a perspective that allows for similar analyses of communication in different modes, such as writing and image.

Social semiotics theory builds on the idea that no sign used for meaning-making, regardless of mode, has meaning in itself outside the context where it is used. From this perspective, every choice of sign is seen as a result of social, cultural, and situational factors in the context of the communicative situation. Situational factors also include the participants, modes, and resources that are available in the situation; in this study, the teaching and learning practices in a primary science classroom. In addition, the participants in a communicative situation are considered to be in mutual interaction. Therefore, anyone who creates a text makes choices of content and resources to express that content (e.g., words, images) based on what is perceived as functional in the communicative situation.

At the same time, all communication is related to conventions that have developed over time in cultural and social contexts; for example, in classroom interaction in physics where the conventions concern subject content as well as how different resources are used when communicating within the subject. Thus, from a social semiotic perspective, choices concerning (1) interaction within a discipline and a school subject, and (2) conventions for content as well as language structures and other resources, are discipline-specific. Therefore, questions about interaction and conventions developed within a school subject are relevant to make explicit in all teaching practices at school, to enable pupils and students to develop their disciplinary literacy; that is, discipline-specific ways of communicating in the discipline [27,28].

In the present study, we used analytical tools developed within social semiotics, including systemic functional linguistics (SFL) [25,29]. Within SFL, form (e.g., linguistic choices or choice of image) and function are not seen as independent of one another, meaning that the choice of form will always affect the content expressed. The SFL theory offers ways for analyzing contexts (e.g., the classroom interaction) as well as texts, from three perspectives. For the context analysis there are three register variables: field (content), tenor (voices), and mode (resources). Field refers to what the situation is about as well as the action in focus. Tenor concerns the relationships between the participants (e.g., teachers and students). Mode concerns the resources used in the interaction (oral or written language, gestures, images, etc.) and their function in the meaning-making process [25]. For text analyses, three metafunctions correspond to field, tenor, and mode: (1) what experiences of the world are represented in the content of the text (ideational metafunction), (2) how social relationships are created in the text between the one who produces it and the one who interprets it; for instance, in terms of how choices of lexico-grammar or visual representations contribute to an authoritative voice (interpersonal metafunction), and (3) how the text is organized; how words, sentences and other resources, like images, are put together to create cohesion (textual metafunction) [25,29,30].

3. Data and Participants

This qualitative study is part of a larger research project concerning physics education in Swedish primary schools [31], where we followed the regular physics classroom activities in a primary school during teaching on the content area of "light". Hence, we did not influence the content or design of the lessons.

The dataset used in the present study involves one teacher's work on shadow formation in a mixed-gender grade 5 classroom (27 pupils aged 10–11 of which 25 pupils consented to participate). The teacher was a relatively newly educated science teacher for the age group in question and had worked at the same school for about a year before the project started. The lesson in focus here, which dealt with light sources and shadow formation, was the first lesson out of six in the content area. The other lessons concerned, for instance, reflection and light beams. Hence, this lesson was the only one targeting shadow formation. The main source of data used in this study consists of the 25 pupils' individual worksheets on shadow formation which were used during a hands-on activity. We have also video recorded all lessons during teaching of the content area. These recordings were the basis for an overall analysis of the context in which the worksheets were used. Hence, they function as background data for the present study.

During the data collection, two researchers were present in the classroom. They took a passive role and did not participate in the teaching as such. The pupils worked both individually and in groups of three to four. In addition to individual work and group work, the teacher also conducted whole class reviews of central topics (e.g., introducing the hands-on-activities). When the pupils investigated light and shadow in groups, they used an electric torch as a light source along with other objects (e.g., pencil, eraser, books, etc.) that were used to block the light in order to create shadows.

In the results section, we use examples from pupils' worksheets. These texts were translated from Swedish into English with an aim to reflect the linguistic choices in the formulations of the tasks in the worksheet and in the pupils' written expressions, sometimes resulting in non-idiomatic English. Also, we have followed the pupils' punctuation marks.

4. Analytical Procedures

In this study, the worksheets as well as the interaction in the teaching practice were studied with general tools from SFL [25,30,32–34]. To give an overview of the context in which the worksheets were used, the situational context is described in regard to the three register variables mentioned above, namely field (content in focus), tenor (the relationships between participants), and mode (the resources used in the interaction).

The worksheets were analyzed in regard to the three metafunctions. To shed light on the content expressed through lexico-grammatical choices in writing and the choices of resources in the images in the pupils' worksheets, our point of departure was the ideational metafunction [29]. A transitivity analysis was done for all 25 worksheets. The starting point in transitivity analyses is to define the process types used, as they constitute the core regarding what is 'going on' in the text. There are six process types: material (something is happening, or someone is acting in the physical world, e.g., shine, stop, come), existential (indicates that something exists, e.g., 'there is a shadow on the wall'), relational (shows the relation between concepts, e.g., 'the shadow is big' and 'that is the shadow'), verbal (e.g., say, explain), mental (e.g., see, think), and behavioral (e.g., yawn). In our analyses, we have merged existential processes with relational processes, in line with what is commonly done in Scandinavian SFL-research [35].

Processes are connected to different types of participants, for instance who or what is acting or exposed to an action. Material processes are commonly connected to the participant type's actor (the one who does something) and goal (the one being done to), e.g., 'the sun shield (actor) blocks the sunlight (goal)'. In existential processes, the participant is the thing existent, e.g., 'there is a shadow (existent) on the wall'. In relational processes the participants are carrier and attribute, e.g., 'the shadow (carrier) is big (attribute)', or token and value, e.g., 'that (token) is the shadow (value)'. Processes can also be related to circumstances, in terms of time, location, ways of doing something, et cetera. In the expression 'there is a shadow on the wall', the circumstance 'on the wall' gives information about location.

The transitivity analysis was also carried out concerning the images, where for instance an arrow can be regarded as a material process showing a movement [30]. Participants are depictions of, for instance, a pencil, the sun, a shadow and so on. Image as a mode has specific affordances to show how participants are spatially related to one another and to show circumstances regarding location. In contrast, written words are more apt for expressing other circumstances such as cause ('because ... ') and condition ('if the object lets ... '). For one of the tasks in the worksheet, the pupils combined image and writing. An analysis was made regarding the interplay between image and writing, for instance regarding the content given in different modes [33,36].

The analyses of the textual metafunction concern the cohesion in the pupils' responses, e.g., how the text unfolds from one sentence to the next, or how different resources are combined. Here we analyzed what acts of writing [37] the pupils used (cf. school genres in [2]). Common acts of writing in science texts are 'explain' and 'describe' [2]. Acts of writing have certain characteristics, for instance in regard to word choices like 'because', or 'therefore' (explain), or attributes assigned to objects (describe). We also analyzed how writing and image were used in combination. Furthermore, we related the pupils' responses to the common three-part structure of a scientific explanation: premise, reasoning, and outcome (cf. PRO, [38]).

In the case of shadow formation, the three parts would be the following:

P—Light travels in a straight line, a continuum.

R1—Light shines onto objects.

R2—Opaque objects block the light from moving in a continuum.

R3—Shadow is absence of light.

O—When an object blocks the light from moving in a continuum, a shadow will be formed.

The PRO-structure includes the key aspects that one needs to relate to when explaining shadow formation. Implicit in the structure is the existence of another key aspect, namely that there must be a light source that sends out light.

The analysis of the interpersonal metafunction was performed in terms of speech functions, which concern giving and demanding information and goods and services. Linguistically this can be done through statements, questions, commands, and offers [39] (there is no typical way of expressing an offer, instead this can be done through the same structures as the other speech functions; cf. 'You can have this book', 'Do you want this book?', and 'Take this book!', which are all offers). In line with Kress and van Leeuwen [30], the drawn images were analyzed in terms of offer and commands. Further, we comment on the textual choices in terms of their relation to the discourse of science, for instance whether the choices in writing and image were directly connected to everyday experiences (including the hands-on activity), or rather connected to disciplinary experiences and language, for instance through scientific terminology in writing, or images resembling scientific diagrams. For that part we reconnect to the analyses of the other two metafunctions. Altogether, the analysis concerning the interpersonal metafunction reveals how the pupils are positioned and position themselves in the worksheets, for instance as knowledgeable in the field.

Finally, we investigated what key aspects of shadow formation that the students included in their texts. Here we mainly drew on the PRO-structure and the transitivity analysis.

5. Results

In the subsequent paragraphs, we first provide an overview of the classroom interaction based on the register variables, field, tenor, and mode, presented above. We then present the results of the analysis of the pupils' responses in the worksheet concerning the three metafunctions: the ideational (in this case based on transitivity analysis), textual, and interpersonal metafunctions. The results presented regarding the ideational analysis are the most extensive, since the content is at the core of science education. Finally, we give an overview of the worksheets in regard to the extent to which they include the central aspects of shadow formation.

5.1. Description of the Situational Context—Register

The field in the situation where the worksheets were in focus was strongly connected to the hands-on activity of creating shadows. In the worksheet that accompanied the hands-on activity, the pupils were asked to explain shadow formation through writing and drawing. In a relatively short introduction to the lesson (approximately 6 min.), the teacher had talked about different light sources, but she did not mention shadow formation, light beams or that you can represent light beams visually, for example as an arrow. Neither did she talk about how to create explanations in written words and drawings, nor about the affordances of different semiotic modes in explanations. Hence, the pupils were expected to solve the tasks in the worksheet without the teacher introducing linguistic or other conventions in the science disciplines or supporting the pupils' in how to solve the tasks. Instead, this activity appears mainly to function as a means of engaging the pupils in the field.

The tenor in the hands-on activity situation was characterized by interaction between the pupils in small groups, and occasionally between the teacher and pupils. The pupils were highly engaged in the activity, creating shadows by directing the light from the torch on their hands, erasers, and other available concrete objects. When the teacher took part in the small group interaction, she dominated the interaction by applying the common IRE pattern (initiation–response–evaluation), typical for an authoritative approach [40]). Thereby, she was in control of the situation and only when the pupils were working and interacting with each other on their own (e.g., the hands-on activity on shadow formation), could they be said to take control.

The mode was characterized by the use of spoken language, gestures, and bodily action. During the hands-on activity, these communicative resources were further accompanied with an electric torch and other objects, such as pencils and hands, to create shadows. The objects (e.g., torch and pencil), the phenomenon (shadow formation), and the hands-on activity itself (creating shadows) constituted a basis for the pupils when expressing their meaning-making in spoken words, linking their ideas into a coherent text. The hands-on activity and their oral meaning-making supported the pupils when construing their ideas of shadow formation in written words and drawn images in the worksheets.

5.2. The Worksheets

The worksheet consisted of a number of tasks. First there was an instruction to use an electric torch and hands to create shadows. Then three tasks involving text creation followed. Two were questions to be answered through writing ("Why does it become a shadow?" "Why does it not become a shadow?"), implying explanations, while the final task was to explain how shadows are formed by drawing an image. The assignment as a whole represented the teacher's voice and positioned the pupils as knowledgeable by expecting them to be able to come up with solutions to the tasks. As mentioned, all 25 worksheets were analyzed. Out of these we use six worksheets as illustrations to our findings (Figures 1–6). These six texts represent common ways of responding to the tasks, though two of them are relatively advanced in terms of both the written and drawn explanations (Figures 1 and 2).

Skuggbilder

Er uppgift är att med hjälp av en ficklampa och era händer skapa olika skuggor.

Varför blir det skugga?

Pennan stoppar ljuset, då ljuset inte kan ta sig igenom pennan. Då syns pennan i ljuskonet. Det blir då skugga.

Varför blir det inte någon skugga?

Inget stoppar ljuset, så att ljuset kan lysa utan skugga.

Förklara hur skugga bildas genom att rita en bild

Images of shadows (Text 1)

Your task is to form different shadows using a torch and your hands.

Why is a shadow formed?

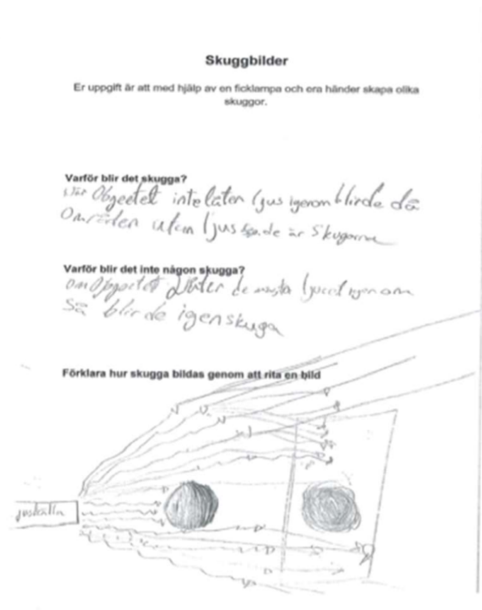
The pencil stops the light, as the light cannot get through the pencil. Then the pencil is visible in the light. Then it becomes a shadow.

Why is no shadow formed?

Nothing stops the light, so that the light can shine without shadow.

Explain how shadows are formed by drawing an image Written clarifications/explanations: Top (stop for the light); middle (shadow); bottom (shines on the edges); Within brackets: (The light comes at the front and not on the back)

Figure 1. Pupil text 1.



Images of shadows (Text 2)

Your task is to create different shadows using a torch and your hands.

Why does it become a shadow?

When the object does not let light through, then there will become areas without light. they are the shadows

Why does it not become a shadow?

If the object lets the slightest light through, there will become no shadow.

Explain how shadows are formed by drawing an image Written clarifications/explanations: "light source"

Figure 2. Pupil text 2.

Images of shadows (Text 3)

Your task is to create different shadows using a torch and your hands.

Why does it become a shadow?

If something comes in front of the light, a shadow is formed

Why does it not become a shadow?

Because nothing is in the way.

Explain how shadows are formed by drawing an image.

Figure 3. Pupil text 3.

Images of shadows (Text 4)

Your task is to form different shadows using a torch and your hands.

Why is a shadow formed?

Because something gets in the way of the light.

Why is no shadow formed?

Because nothing is in the way of the light.

Explain how shadows are formed by drawing an image above the circle "light source"; hand on the circle "covers the light source", arrow pointing to lines "light" and arrow pointing to the square "wall".

Figure 4. Pupil text 4.

Images of shadows (Text 5)

Your task is to create different shadows using a torch and your hands.

Why does it become a shadow?

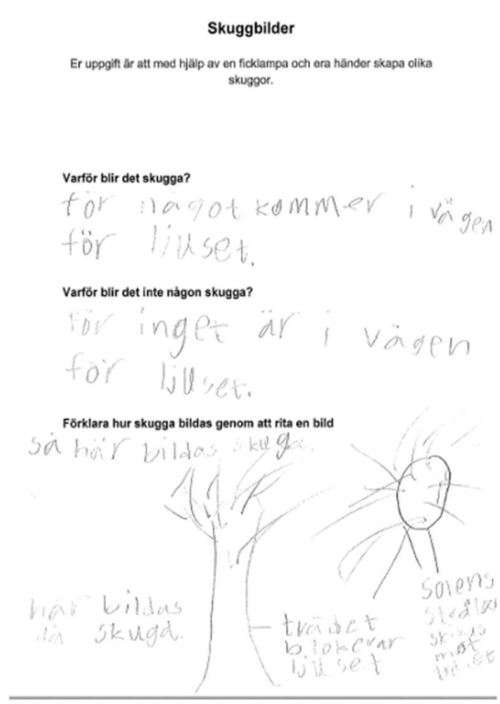
It becomes a shadow when the sun shines on something, e.g., a mailbox.

Why does it not become a shadow?

It becomes no shadow when

Explain how shadows are formed by drawing an image Image: mailbox – the sun

Figure 5. Pupil text 5.



Images of shadows (Text 6)

Your task is to create different shadows using a torch and your hands.

Why does it become a shadow?

Because something gets in the way of the light.

Why does it not become a shadow?

Because nothing is in the way of the light.

Explain how shadows are formed by drawing an image above the tree "This is how a shadow is formed"; left to the tree" shadow is formed here"; right to the tree (with a labeling arrow/line) "the tree blocks the light"; under the sun "the sun rays are sent towards the tree".

Figure 6. Pupil text 6.

In all of the examples shown in Figures 1–6, the pupils have responded, more or less, to all three tasks where they were supposed to write or make drawings. However, in total, not all of the pupils' texts responded to all three tasks. One pupil did not respond to the question of why shadows are formed ("Why does it become a shadow?"), while three pupils did not respond to the question why shadows are not formed ("Why does it not become a shadow?"). All 25 pupils made drawings as a response to the last task.

5.3. Ideational Metafunction: Content Analysis of Written Explanations

Regarding the ideational metafunction, we made a transitivity analysis of the written words starting with the process type. In all of the responses to the two 'why' questions, the processes are material or relational, which is in line with the language of the discipline [1]. Recurring examples of material processes in the responses are "stop" (e.g., Text 1), "get", or "let through" (Text 1 and 2) and "comes" or "gets in the way" (e.g., Text 3, 4, and 6). Some of the material processes are 'doing' processes, hence, implying an actor who does something, for instance an indefinite "something" that does not "let through" the light (Text 2). Other material processes are 'happening' processes, for example "something" that "comes" in front of the light (Text 3 and 6). The material processes are expressed through everyday words (cf. "come in the way" with the more subject-specific "block"). Relational processes are used in 14 texts, such as "become" (Text 1 and 2) and "is/are" (Text 1, 3, 4, and 6). Four texts contain the expression "are formed", though, which is a more academic choice than 'become'. Many of the relational processes imply that something exists (i.e., existential processes according to Halliday and Matthiessen, [29]), for instance an object, e.g., a pencil, or that something is formed, usually a shadow. In some of the more elaborate responses, the starting point is a couple of material process (MP) followed by a relational process (RP), for example, "The pencil stops (MP) the light . . . cannot get through (MP). Then the pencil is (RP) visible in the light. It becomes (RP) a shadow" (Text 1).

Each process has one or more participants connected to it and as mentioned, the participants take on different roles depending on process type. In the pupils' texts, participants connected to the material processes are often on the one hand an indefinite "something"

(Text 3, 4, and 6) or "nothing" (Text 3 and 6) and on the other hand more specific everyday objects, such as "pencil" (Text 1). In addition, some pupils mention a more general "object" (e.g., Text 2). The participants at times function as actors in the material process, with "light" having the role of goal (i.e., the object of the process). Examples are "The pencil (actor) stops the light (goal)" (Text 1) and "the object (actor) does not let the light (goal) through" (Text 2). The latter example ("let through") implies intentionality or agency of the first participant (in this case "the object"') (cf., anthropomorphism, [41–43]. Relational processes can relate a participant to another participant, or to a circumstance. In the pupils' responses, the relative process "become" is commonly combined with "shadow", which is subject-specific even though it is also used in everyday language (Text 1). Other common examples of relational processes are when an indefinite "something" or "nothing" is combined with a circumstance indicating location: "nothing is in the way of the light" (Text 4) or "nothing is in the way" (Text 3).

An important aspect of explanations—in this case why shadows are formed, or not formed—is to express some kind of causation (see [38]. A common way of doing this is through circumstances indicating cause (e.g., because, therefore) or condition (e.g., if . . .). Many of the responses only contain a causal expression, for instance, "Because something gets in the way . . . " (Text 4 and 6). Others contain circumstances indicating condition, such as: "If the object lets the slightest light through" (Text 2) and "If something comes in front of the light" (Text 3) followed by a comment that a shadow is formed or not formed. However, seven texts instead contain temporal circumstances, for example, "When the object does not let light through . . . " (Text 2), which can be viewed as an implicit way of indicating causation. Another way of explicitly expressing causation is through processes such as "stops" (Text 1) and "lets through" (Text 1 and 2, cf., [1] p. 73).

Regarding the content expressed in writing, taken together, the analysis reveals that many of the students through everyday lexico-grammatical choices express that everyday objects or indefinite 'somethings' hinder—or do not hinder—the light.

5.4. Ideational Metafunction: Content Analysis of Drawings

The final task, to explain shadow formation by drawing an image, may seem relatively straightforward. However, the formulation of the task implies that the image should be an explanation: "Explain why shadows are formed by drawing an image". Hence, it is expected that the drawing should show some kind of causation. However, due to the modal affordance of image (e.g., Kress [26]), to draw an image would be particularly apt for showing spatial relations, while words are more apt for expressing temporal aspects, cause, and consequence. Therefore, a combination of writing and image would perhaps be more functional than an image only; also, to draw an image in two dimensions that captures something that pupils experience in a three-dimensional room can be challenging. Before the hands-on activity, the teacher told the pupils that if they found it difficult to draw an image, they could also use writing. An overall analysis of all 25 responses to this task revealed that 16 of the drawings combined images with written elements. In 9 of these 16 responses, the written elements contained comments such as "The light comes on the front and not on the back" in Text 1 and "Here a shadow is created" in Text 6. In the remaining 7 drawings, writing is used to label images, such as the word "light source" in Text 1 and Text 4 and "mailbox" in Text 5.

The transitivity analysis of the responses to this task reveals a similar pattern regarding processes, as was the case for the written responses to the 'why' questions. In the 9 texts containing comments in writing, the processes are mainly material, such as "covers" (Text 4) and "shines" (Text 1) and in some cases relational, such as "become" (Text 6). Twenty-two of the images contain arrows or drawn lines that imply material processes (Text 1, 2, 4, 5, and 6). These arrows typically depict traveling light beams of some form: either sun rays or light beams from a light source towards an object. This is in line with Kress and van Leeuwen's [30] classification of narrative images, typically containing arrows, lines, or gazes. Yet, a number of arrows and lines in the drawings also seem to imply relational processes, for instance a written word and an image of an object connected by an arrow or a line, with the written word functioning as a kind of label (cf. "this is a shadow") (Text 1, 4, and 5). Such arrows either point from the word towards the image or the other way around (cf. classificational representations, Kress and van Leeuwen [30]).

The participants in the drawings vary in both numbers and character, and they are represented both through image and writing. The participants depicted through image typically represent concrete physical everyday objects, such as pencils and hands, or science phenomena such as light beams and shadows (Text 1, 2, 4, and 5). To a great extent, the images of concrete objects that block the light depict other objects than those used in the hands-on activity (exceptions are, for instance, the images in Text 1 and 4). The participants given in writing are mainly labels clarifying what is depicted through an image and hence they often consist of concrete objects (e.g., "mailbox", "pencil") or the phenomenon "shadow". As not all images are combined with labels, there are more participants given through image than words. The participant "stop for the light" (Text 1) pointing at a line in front of a depicted pencil and the comments given in Text 6 are evidence of the challenge of explaining shadow formation through image only.

In many texts, the circumstances shown through image imply location, for instance the shadow cast on the wall (Text 2 and 4), behind the cube (Text 3), behind the pen on the desk (Text 1) or behind the mailbox (Text 5). In Text 6, the circumstance indicating location, "here", is only expressed in writing. As mentioned, the formulation of the task was to explain how shadows are formed, hence implying some kind of causation. In Text 6, the causation is given through a number of statements in writing which together build up a chain of processes. Arrows can be one way of showing causation and a number of texts use arrows in that way, such as Text 1 and 2, with arrows from a light source depicting light beams which are obstructed by an object behind which a shadow is cast. The pupil behind Text 1 appears to have felt a need to combine the everyday object (pencil) with some kind of scientific depiction: a straight line that accentuates that the light beam is blocked. The combination of the line and the participant given in writing, "stop", implies a causal relationship. The image in Text 2 resembles a scientific diagram and this is the only text where the image appears to explain the phenomenon in a relatively abstract fashion. In other images it was less evident that the arrows actually indicated causation.

Regarding the interplay between image and writing, the most prominent pattern is that writing is used for labels as a way of clarifying what has been depicted. In Text 6, on the other hand, writing and image are integrated, with writing giving explicit information about different processes (e.g., "The tree blocks the light"). An interesting finding is that in some cases, a material process is given in writing, while the participant involved in the process is depicted in image. One example can be seen in Text 1, with a depiction of light beams (participant) combined with the comment "shines (MP) on the edges (circumstance)", where "the edges" probably relate to the outline of the pencil. Another example can be seen in Text 4, where a drawn line connects a depicted hand (participant) with the written word, "covers" (MP). These are examples of image and writing forming a kind of clause in a multimodal ensemble.

5.5. Textual Metafunction: Analysis of Text Structures

In the following, we first comment on acts of writing, which are then connected to PRO patterns. In science, the acts of writing 'explain' and 'describe' are commonly used. As mentioned, in this worksheet, the pupils were asked to give explanations both in writing (the two 'why' questions) and in the last task, by drawing an image. A description can be included in an explanation, however, for instance function as a point of departure for the explanation.

As was noted in the transitivity analysis of the two 'why' questions above, a majority of the texts contain causal expressions, hence they function at least to some extent as explanations, e.g., "because something comes in the way for the light" (Text 6). Some of the more elaborate responses as to why shadows are formed also begin with material processes followed by a relational process, e.g., "The pencil stops (MP) the light, then the light cannot get through (MP) the pencil/ . . . /Then it becomes (RP) a shadow" (Text 1). Such a formulation could be seen as an attempt to apply science conventions in terms of first using material processes as a point of departure for an explanation, based on the hands-on work, with a sequence of events, followed by a note to establish a conclusion through a relational process.

Regarding the last task, we have mentioned that a way of overcoming the challenge of explaining through a drawing is to use arrows to depict causal relations, or to make causal relations explicit by combining the image with writing. We noted that many texts contained arrows or lines. These can indeed be considered attempts to explain the phenomenon. The drawings in Text 1 and Text 2 (which are the most elaborate texts in the data) and Text 4 are considered to be functional explanations, even though the actual explanatory part is more or less implicit, apart from the diagrammatic image in Text 2, which functions as an explanation. We also mentioned that 9 texts, e.g., Text 6, contain comments in writing that could be regarded as attempts to explain the phenomenon, and also that image and writing at times were connected in 'clauses' containing at least a participant (through image) and a process (through writing). Text 4 is a clear example of this. Other texts in the data are more implicit regarding the causation, for instance Text 5, where neither arrows, nor a written comment is used.

Above, we suggested that shadow formation could be explained through the following three-part structure of a scientific explanation, PRO:

P—Light travels in a straight line, a continuum.

R1—Light shines onto objects.

R2—Opaque objects block the light from moving in a continuum.

R3—Shadow is absence of light.

O—When an object blocks the light from moving in a continuum, a shadow will be formed.

In our data, we noted that a number of texts included one (e.g., Text 3) or more aspects of reasoning (e.g., Text 1 and 2) and that the final part of the outcome, that a shadow is formed, was often expressed. However, in this worksheet, the second part of the outcome was mentioned in the task (i.e., that a shadow is, or is not, formed). The fact that this part of the outcome is already mentioned can explain why some pupils omitted it in their responses, e.g., Text 4, "Because nothing is in the way of the light". One example with expressed reasoning and outcome is the response to the first 'why' question in Text 2: "When the object does not let light through (R2), then there will become areas without light, they are the shadows (O)".

5.6. Interpersonal Metafunction: Analysis of How Pupils Position Themselves

Concerning the interpersonal metafunction, all of the 25 texts consisted of statements, hence giving information, which is one way of showing authority. Additionally, all responses to the last task showed some sort of diagrams, corresponding to offers (cf. Kress and van Leeuwen [30]), through which a potential reader is offered information. As is evident from the above analyses, some diagrams were more elaborate than others, for instance the ones in Text 1 and 2, which both depicted a light source sending out light beams that were stopped by an object and a shadow cast on a surface, while others only showed one or more objects and a shadow (e.g., Text 3).

The transitivity analysis revealed that the lexico-grammatical choices in the texts to some extent correspond to the language of science, such as the use of material and relational processes. However, as noted above, the processes as well as participants are everyday words such as the processes "stop" and "let through" and participants such as an indefinite "something" or "nothing", or everyday objects, such as "pencil", rather than scientific choices, such as the material process "block". In a couple of texts, the choice of participant was more in line with the language of science, such as "object" or "area" (Text 2). The drawings, too, generally contained depictions of everyday objects, such as an eraser, a tree, or a human being, often in combination with a sun. Here, Text 2 stands out, with a more abstract diagram resembling diagrams used in the discipline. The responses to the two 'why' questions in this text were also closer to the language of science than the rest of the texts, with choices such as "object" and "areas without light". As mentioned, most texts included one or more aspects of the PRO structure. Hence, taken together, the pupils to some extent showed authority in relation to the subject and a potential reader, through their lexico-grammatical choices, text structures, and diagrams. However, Text 1 and, in particular, Text 2 stand out as more elaborate than the others and they are also closer to the language of the discipline.

5.7. Evaluation of the Scientific Content in the Responses

Table 1 presents an overview of the pupils' responses in relation to central aspects of premise, reasoning, and outcome (PRO) for shadow formation.

Table 1. Overview of responses related to premise, reasoning, and outcome (PRO). Numbers given correspond to the number of texts that include the different aspects of PRO. As mentioned, we consider 'light source' as a key aspect, even if it is not explicitly stated in the premise.

	Light Source	**Light Travels in a Straight Line P**	**Light Beam Shining on Object R1**	**Object Blocking Light R2**	**Shadow R3 + O**	**Total Number of Adequate Answers to Each Task**
Why does it become a shadow?	9	0	17 (e.g., "the light, shines")	22	18	23 (7 implicit)
Why does it not become a shadow?	7	0	12	15 (e.g., "nothing")	7	12 (8 implicit)
Explain through drawing	22	22	22	23	19 (depicted object)	15

In a majority of the texts (23 out of 25), the pupils included the key ideas of shadow formation when responding to the first 'why' question, on why shadows are formed: a physical object will hinder the light from moving in a continuum. Out of these 23 responses, 7 responses were to some extent implicit in regard to some aspects of the content. Examples are responses that did not include a light source or light beams, such as "If something comes in front a shadow will be created" (not shown in the examples). Responses such as "The sun does not shine then there will be shadow" (not shown in the examples) do not connect to key science ideas, but instead to everyday experiences of finding shade where the sun is not shining (in Swedish, the same word, skugga, is used for 'shade' and 'shadow'). In opposition to the high rate of scientifically adequate responses to the first 'why' question ("Why does it become a shadow?"), only 12 responses to the second question ("Why does it not become a shadow?") included key aspects of shadow formation. These include partly implicit responses based on the first 'why' question (e.g., Text 3, "because nothing is in the way"). It is also clear that many pupils used the first response as a kind of template for the second one. One such example can be seen in Text 4 ("Something gets in the way . . . ", "Nothing is in the way . . . "). The remaining 13 responses are either non-responses or were explanations such as "There is no light" or "If there is no light nothing can stop it" (not shown in the examples). These findings indicate that it might be more challenging to explain the absence of shadow than to explain why shadows are formed. In regard to the third task, to draw an image that explains how shadows are formed, a majority of the pupils included a light source, light beams that travel in a straight line, and objects that can hinder light beams, and depictions of shadows, resulting in 15 drawings that function as explanations of shadow formation (Table 1). It is worth noting that more pupils managed to elaborate, express, and provide written explanations to shadow formation (the first 'why' question) compared to when the pupils were prompted to draw an image of their explanation. In addition, 16 of the drawings combined images with written elements as a way to clarify the meaning of the images, for instance, when writing was used to describe what was depicted through image, such as "Here a shadow is created" in Text 1, and the label "mailbox" in Text 5.

6. Summary and Discussion of Findings

With the present explorative study, which builds on detailed analyses of pupils' multimodal text work in a prefabricated worksheet connected to a hands-on activity about shadow formation, we seek to contribute to research about how such texts can be used as a resource for pupils to make meaning through multimodal texts and thereby position themselves as knowledgeable in science. Specifically, we intend to add to the body of research that builds on the fact that science discourse is highly multimodal in nature, and which concludes that, as a consequence, both teachers and pupils need to develop an awareness of the discipline's ways to communicate and make meaning of the content, through different semiotic modes (e.g., writing, image) as well as models and various representations of science phenomena (e.g., [2–4,6,7]).

In the following, we reconnect to the findings in light of the three metafunctions, the interpersonal metafunction, the ideational metafunction (transitivity analysis), and the textual metafunction respectively [25,29] as a way to shed light on the characteristics of the pupils' responses in the worksheets. Although the analysis of the ideational metafunction is primarily related to science content, and therefore crucial for understanding pupils' meaning-making in science, the interpersonal metafunction is vital when it comes to showing authority and positioning oneself in the school subject. Therefore, in the following we start with the interpersonal metafunction.

In regard to the interpersonal metafunction, an awareness among teachers about discipline-specific ways to communicate and make meaning of the content may promote their opportunities to focus on science-relevant aspects in text when teaching science. When doing so, they can enable pupils to make scientific meaning through words and images. Thereby teachers can support pupils to position themselves as knowledgeable in science (cf. Schleppegrell [2]). It can be noted that through the worksheet analyzed in this study, the teacher positions the pupils as knowledgeable, as she asks questions that she must have thought they would be able to answer. In other words, she has given them a framework, in terms of tasks, which forms a basic text structure that the pupils are likely to fulfil by adding explanations to show their meaning-making. Through their texts, the pupils positioned themselves as knowledgeable, as they authoritatively made statements about the science content, giving information to the reader through words and visual representations. By creating their own representations of the phenomenon, the pupils also likely deepened their science learning [7,44]. In addition, by relating the pupils' responses to the PRO structure [38], we showed how the responses contained at least some of the key aspects of shadow formation, which is another way of showing authority in science.

Moving on to the ideational metafunction, the transitivity analysis revealed that a majority of the pupils used everyday language when showing their knowledge about the key aspects. Some of the more elaborate responses typically started with an expression containing a material process related to an actor and a goal: "The pencil (actor) stops (MP) the light (goal)" (Text 1), followed by another material process, an actor and a goal (e.g., "as the light (actor) cannot get through (MP) the pencil (goal)"). The actual result (shadow formation) was often given through a relational, existential, process combined with 'shadow' and either a temporal or a causal circumstance: "Then (temporal circumstance) it becomes (RP) a shadow (existent)". The material processes were concrete, expressing what happened in the hands-on activities, whereas the following relational process described the result.

Connecting the ideational analysis to the textual metafunction, the text structures in the elaborate responses can be viewed as the writing act 'explain' [37]. However, the transitivity analysis showed that the choice to express causation through a circumstance indicating cause or consequence (including, e.g., 'therefore', 'as a result') resulted in an explicit explanation, while a temporal circumstance (e.g., 'then') made the explanation implicit. Similar to the pupils' use of everyday language in their written responses to the two 'why' questions, the transitivity analysis revealed that the depicted participants in the pupils' drawings were mainly everyday objects, at times combined with a clarifying label, e.g., an image of a mailbox combined with the word "mailbox" (Text 5). In the drawings, processes were depicted through arrows and lines and they appeared to be used for both material and relational processes where arrows that were analyzed as material processes showed the direction of light beams, while arrows analyzed as relational processes were arrows connecting a depiction and a labeling word. In cases where arrows showing material processes depicted light beams towards an object that hindered the light beam, resulting in a shadow behind the object (cf. PRO, [38]), the image functioned as an explanation (e.g., Text 1 and 2). Text 2 which was the most elaborate worksheet, was the only one where the PRO structure was given without any use of writing, but instead a schematic image, resembling diagrams in science. As mentioned, given the affordance of image, it is a challenging task not only to describe, but also to explain a phenomenon through image. Most pupils solved this challenge by supplementing the image with writing. However, in relation to the explicit task of drawing an image to explain how shadows are formed, only one pupil managed to solve this task (Text 2).

We do not know the reason why the teacher asked the pupils to provide explanations to the phenomenon both by writing and by drawing an image. Connecting to Gardner [20] and at the same time taking the affordance of image and words into consideration, a possibility would have been to ask the pupils to describe the concrete, action-based hands-on activity by drawing an image and thereby show spatial relations as a kind of bridge from the concrete, hands-on task to the more abstract, language-based task. Instead, in the worksheet the pupils were asked to use images in an abstract way, namely, to show logical relations. As already mentioned though, the teacher did not discuss with the pupils how visual resources such as arrows could be utilized in a visual explanation, or to what extent a combination of image and words could be functional. Instead, she commented that the pupils could use words as well, if they found it difficult to respond through image only.

As mentioned above, the first two tasks were formulated as 'why' questions. Such questions direct the acts of writing towards explanations in words, though in an implicit manner. The third task, however, explicitly asked for an explanation to be given through image. We have seen that many of the pupils structured their explanations more or less in line with what could be expected at least if we consider (1) the age of the pupils, (2) the lack of explicit teaching concerning textual structures and choices (acts of writing, images, and lexico-grammar), (3) the lack of attention to the aim and the potential reader of the text in the worksheet, and (4) us being benevolent readers of the texts. However, for pupils to be able to use their full potential when creating texts for making meaning about content and to position themselves as knowledgeable, teachers may need to give them support.

Implications

In the following, we discuss two implications for education that can be drawn from the present study. First, the result indicates the value of teachers' and pupils' text competence, both in general, concerning for instance, the affordance of different modes, and the function of different writing acts, and more specifically concerning the subject-specific ways of communicating science content. Therefore, teachers need to be aware of the importance of how tasks are formulated in, for instance, a worksheet to be able to support the pupils' meaning-making about the content, and also to give them fair opportunities to show their knowledge in multimodal texts. Second, pupils may benefit from teaching practices in which text conventions in science as a school subject are made explicit for the pupils, that is, to discuss and make visible how form and content are closely interconnected. As we saw in the overview of the classroom interaction, the teacher did not discuss with the pupils how explanations can be structured in writing or how different resources such as writing and image have different affordances and therefore might need to be combined in order to create functional explanations. In the paragraphs below, we discuss these two implications.

Regarding task formulations, in this study the tasks functioned as a kind of frame for the pupils. In the worksheet, explanations were requested, on the one hand, implicitly through the interrogative 'why' in tasks 1 and 2 and on the other hand, explicitly in the formulation of the third task ("Explain how . . . "). Most pupils did formulate explanations to the first 'why' question, though fewer responded to the second one, or that explanation was more or less implicit (e.g., Text 3). We do not know why this was the case. It could be that pupils normally are expected to explain why a phenomenon occurs, but more seldom why it does not occur; also, they had already explained why a shadow is formed. Hence, that response might be viewed as though it implies the explanation to the second 'why' question. Furthermore, many pupils used the first response as a kind of template for the second response. In the responses to the second question though, they excluded parts that were valid for both explanations (e.g., light source, light beams). Therefore, one cannot draw conclusions from the responses in one part of the worksheet without recognizing the text as an entirety. In addition, in our data, pupils not only omitted information presented in a former question, they also drew on the entire teaching context, including the hands-on activity, making important aspects of the content implicit in their answers. This indicates that pupils could benefit from teachers being clear about the boundaries for the text; that is, if the worksheet in its entirety is to be considered as the text or if every task in the worksheet should be seen as a text. The reason why the pupils' texts to some extent were implicit could also be explained by the pupils' thinking of the teacher as the reader of the texts, a reader that had knowledge of the context and the content. If pupils are told to create texts that are directed to someone who is not familiar with the content, for instance pupils in a lower class, they need to be more explicit, hence also showing their own understanding of the phenomenon more explicitly.

The last task in the worksheet was to explain shadow formation by drawing an image. As mentioned, this is a challenging task, given the affordance of image. In the present study, only one pupil (Text 2) created a scientifically valid explanation through image only. When pupils are asked to use images in their texts, teachers and pupils need a mutual understanding as to what content can be expressed through image (e.g., in this case a descriptive image of hands-on materials and science phenomena such as light beams and shadow) and to what extent writing might be needed as a support, for instance for an explanation of the phenomenon to be explicit.

The conclusion above points to the second implication, namely to make explicit conventions that can support pupils when creating texts. From a social semiotic point of view, form and content are closely interconnected. Furthermore, texts in different disciplines, such as science, are domain-specific where certain choices of resources (words, structures, diagrams) are used in specific ways (e.g., Wellington and Osborne [6]). Examples are visual models of science phenomena, text structures, different lexico-grammatical choices to express cause and consequence, or the use of precise disciplinary vocabulary. Therefore, it has been repeatedly argued that teachers can—or even need to—support students' knowledge development by integrating content with how language is used in different disciplines [28,34,45]. One possibility then is to discuss how acts of writing, such as explanations and descriptions, can be formulated in line with the conventions of the discipline and in so doing also relate to multimodal aspects, for instance conventions regarding diagrams in science, or potential meanings of arrows. In Text 1 and 2 in this study, the pupils seem to have captured some of the disciplinary conventions related to words, drawings, and text structures that are relevant to use when communicating science. The result does not show whether the use of disciplinary conventions are important for their learning in physics, but by applying the conventions they might increase their opportunities to position themselves as knowledgeable, hence actually position themselves in the discipline [28,34], e.g., by choosing the discipline-specific "block" instead of the more everyday "be in the way of". In this case, both choices are functional in regard to the content, but when making the language of the discipline one's own, pupils might see themselves as more competent in science than if they were to use the more colloquial expression. Some pupils, like the ones behind Text 1 and 2, might themselves notice how texts are formulated and structured to communicate functionally and in a scientifically legitimate way, though for others this needs to be made explicit.

Moreover, texts (in a wide sense) can be used both as thinking tools and to communicate ideas to others. In our study, the function of the texts was not made explicit in the classroom situation, for instance if they were supposed to be used for formative assessment or if they were just supposed to be used as thinking tools and a basis for small group discussions in relation to the hands-on activity. Many of the responses in our study were categorized as implicit in regard to the science content. We were able to do this categorization since we had experience of the whole context and could interpret the pupils' texts in light of the hands-on activity. As mentioned, if the function of a text is to communicate ideas to a person who is not familiar with the context—or the content—it is important that the teacher makes this explicit [34], for the students to be able to consider and choose appropriate resources for their disciplinary texts.

It might appear demanding to teachers of science to include a language perspective in their instructions. However, a consequence of the ideas outlined in this article is that language is always at play—whether the teacher is aware and informed or not—and to make it possible for all pupils to succeed in the subjects, teachers need to make explicit the valued ways of using language to communicate the science content.

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References

1. Halliday, M.A.K. On the language of physical science. In *Writing Science. Literacy and Discursive Power*; Halliday, M.A.K., Martin, J., Eds.; Taylor & Francis Group: London, UK, 1993; pp. 59–75.
2. Schleppegrell, M.J. *The Language of Schooling: A Functional Linguistics Perspective*; Lawrence Erlbaum: Mahwah, NJ, USA, 2004.
3. Lemke, J.L. Multiplying meaning: Visual and verbal semiotics in scientific text. In *Reading Science*; Martin, J., Veel, R., Eds.; Routledge: London, UK, 1998; pp. 87–113.
4. Treagust, D.F.; Duit, R.; Fischer, H.E. (Eds.) *Multiple Representations in Physics Education*; Springer International Publishing: Cham, Switzerland, 2017; Volume 10.
5. Kress, G.; Jewitt, C.; Ogborn, J.; Tsatsarelis, C. *Multimodal Teaching and Learning: The Rhetorics of the Science Classroom*; Continuum: London, UK, 2001.
6. Wellington, J.; Osborne, J. *Language and Literacy in Science Education*; McGraw-Hill Education: London, UK, 2001.
7. Klein, P.D.; Kirkpatrick, L.C. Multimodal literacies in science: Currency, coherence and focus. *Res. Sci. Educ.* **2010**, *40*, 87–92. [CrossRef]
8. Guesne, E. Light. In *Children's Ideas of Science*; Driver, R., Guesne, E., Tiberghien, A., Eds.; Open University Press: Milton Keynes, UK, 1985.

9. Osborne, J.; Black, P.; Smith, S.; Meadows, J. *Light Research Report*; Primary SPACE Project; Liverpool University Press: Liverpool, UK, 1990.
10. Chen, S.-M. Shadow: Young Taiwanese children's views and understanding. *Int. J. Sci. Educ.* **2009**, *31*, 59–79. [CrossRef]
11. Valanides, N.; Efthymiou, I.; Angeli, C. Interplay of Internal and External Representaions: Stundents' Drawings and Textual Explanations about Shadow Phenomena. *J. Vis. Lit.* **2013**, *32*, 67–84. [CrossRef]
12. Euler, E.; Rådahl, E.; Gregorcic, B. Embodiment in physics learning: A social-semiotic look. *Phys. Rev. Phys. Educ. Res.* **2019**, *15*, 010134. [CrossRef]
13. Abrahams, I.; Millar, R. Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *Int. J. Sci. Educ.* **2008**, *30*, 1945–1969. [CrossRef]
14. Hofstein, A.; Lunetta, V.N. The laboratory in science education: Foundations for the twenty-first century. *Sci. Educ.* **2004**, *88*, 28–54. [CrossRef]
15. Domin, D.S. A review of laboratory instruction styles. *J. Chem. Educ.* **1999**, *76*, 543. [CrossRef]
16. Larsson, J. Children's encounters with friction as understood as a phenomenon of emerging science and as "opportunities for learning". *J. Res. Child. Educ.* **2013**, *27*, 377–392. [CrossRef]
17. Ainsworth, S.; Prain, V.; Tytler, R. Drawing to learn in science. *Science* **2011**, *333*, 1096–1097. [CrossRef]
18. Jeppsson, F.; Frejd, J.; Lundmark, F. "Wow, It Turned Out Red! First, a Little Yellow, and Then Red!" 1st-Graders' Work with an Infrared Camera. *J. Res. Child. Educ.* **2017**, *31*, 581–596. [CrossRef]
19. Tang, K.S.; Won, M.; Treagust, D. Analytical framework for student-generated drawings. *Int. J. Sci. Educ.* **2019**, *41*, 2296–2322. [CrossRef]
20. Gardner, H.; Jerome, S. Bruner 1915-. In *Fifty Modern Thinkers on Education from Piaget to the Present*; Palmer, J., Ed.; Routledge: London, UK, 2001; pp. 90–96.
21. Bruner, J.S. *Toward a Theory of Instruction*; Harvard University Press: Cambridge, MA, USA, 1966; Volume 59.
22. Molander, B.O.; Halldén, O.; Pedersen, S. Understanding a phenomenon in two domains as a result of contextualization. *Scand. J. Educ. Res.* **2001**, *45*, 115–123. [CrossRef]
23. Wilmes, S.E.; Siry, C. Science notebooks as interactional spaces in a multilingual classroom: Not just ideas on paper. *J. Res. Sci. Teach.* **2020**, *57*, 999–1027. [CrossRef]
24. Danielsson, K. Learning Chemistry: Text use and text talk in a Finland-Swedish chemistry classroom. *IARTEM e-J.* **2010**, *3*, 1–28.
25. Halliday, M.A.K. *Language as Social Semiotic: The Social Interpretation of Language and Meaning*; Edward Arnold: London, UK, 1978.
26. Kress, G.R. *Multimodality: A Social Semiotic Approach to Contemporary Communication*; Taylor & Francis: London, UK, 2010.
27. Moje, E.B. Chapter 1 Developing socially just subject-matter instruction: A review of the literature on disciplinary literacy teaching. *Rev. Res. Educ.* **2007**, *31*, 1–44. [CrossRef]
28. Bergh Nestlog, E. Disciplinary language—A Question of Content, Voices and Structures in Content-area Texts. *HumaNetten* **2020**, *45*, 185–212.
29. Halliday, M.; Matthiessen, C.M.; Matthiessen, C. *An Introduction to Functional Grammar*; Routledge: London, UK, 2014.
30. Kress, G.; Van Leeuwen, T. *Reading Images: The Grammar of Visual Design*, 2nd ed.; Routledge: London, UK, 2006.
31. Danielsson, K.; Jeppsson, F.; Bergh Nestlog, E. Transformations of Transformations—An Interdisciplinary Study of Pupils' Meaning-Making through Transformations of Representations in Science Classes: Swedish Research Council, Grant Number (2017-03478).
32. Knain, E. *Scientific Literacy for Participation: A Systemic Functional Approach to Analysis of School Science Discourses*; Sense Publishers: Rotterdam, The Netherlands, 2015.
33. Unsworth, L. Image/text relations and intersemiosis: Towards multimodal text description for multiliteracies education. In Proceedings of the 33rd International Systemic Functional Congress, Sao Paulo, Brazil, 10–15 July 2006; pp. 1165–1205.
34. Wanselin, H.; Danielsson, K.; Wickman, S. Analysing Multimodal Texts in Science—A Social Semiotic Perspective. *Res. Sci. Educ.* **2021**, 1–17. [CrossRef]
35. Andersen, T.H.; Petersen, U.H.; Smedegaard, F. Metafunctional Profile: Danish. In Proceedings of the 14th Euro-International Systemic Functional Linguistics Workshop, Lisbon, Portugal, 24–27 July 2002.
36. Danielsson, K. Modes and meaning in the classroom: The role of different semiotic resources to convey meaning in science classrooms. *Linguist. Educ.* **2016**, *35*, 88–99. [CrossRef]
37. Berge, K.L.; Evensen, L.S.; Thygesen, R. The Wheel of Writing: A model of the writing domain for the teaching and assessing of writing as a key competency. *Curric. J.* **2016**, *27*, 172–189. [CrossRef]
38. Tang, K.S. Constructing scientific explanations through premise–reasoning–outcome (PRO): An exploratory study to scaffold students in structuring written explanations. *Int. J. Sci. Educ.* **2016**, *38*, 1415–1440. [CrossRef]
39. Thompson, G. *Introducing Functional Grammar*; Routledge: London, UK, 2013.
40. Mortimer, E.; Scott, P. *Meaning Making in Secondary Science Classrooms*; McGraw-Hill Education: London, UK, 2003.
41. Danielsson, K.; Löfgren, R.; Jahic Pettersson, A. Gains and losses: Metaphors in chemistry classrooms. In *Global Developments in Literacy Research for Science Education*; Tang, K.S., Danielsson, K., Eds.; Springer: Cham, Switzerland, 2018; pp. 219–235.
42. Jeppsson, F.; Haglund, J.; Amin, T.G.; Strömdahl, H. Exploring the use of conceptual metaphors in solving problems on entropy. *J. Learn. Sci.* **2013**, *22*, 70–120. [CrossRef]

43. Taber, K.S.; Watts, M. The secret life of the chemical bond: Students' anthropomorphic and animistic references to bonding. *Int. J. Sci. Educ.* **1996**, *18*, 557–568. [CrossRef]
44. Prain, V.; Tytler, R. Learning Through Constructing Representations in Science: A framework of representational construction affordances. *Int. J. Sci. Educ.* **2012**, *34*, 2751–2773. [CrossRef]
45. Fang, Z.; Schleppegrell, M.J. Disciplinary Literacies Across Content Areas: Supporting Secondary Reading Through Functional Language Analysis. *J. Adolesc. Adult Lit.* **2010**, *53*, 587–597. [CrossRef]