Signs of Learning—Multiple Modes as Support for Interaction in a Linguistically Diverse Physics Classroom

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Abstract: Students’ and teachers’ meaning making in science classrooms is dependent on language in a broad, multimodal, sense, comprising specialized lexicogrammar and ways of using semiotic resources such as models, diagrams, and subject specific symbols. Altogether, the multimodal demands of science can be challenging, in particular for students learning the language of instruction in parallel with the subject content. Yet, multimodal perspectives are scarce in research concerning science learning in linguistically diverse classrooms, where several students are educated in their second language. Drawing on designs for learning theory, the interaction in a linguistically diverse physics classroom was analyzed through the Learning Design Sequence model to investigate the teacher’s design for learning for students’ meaning-making about ‘sound’. Thereto, students’ ‘signs of learning’ regarding subject content and how to communicate content in line with the discourse of science was analyzed. The teacher’s design for learning gave the students opportunities to interact about content by use of different semiotic modes, with gradually higher demands regarding both content and how to express the content which appeared to support students’ development of content knowledge and competency to express this knowledge in line with the discourse of science. However, some of the teacher’s choices appeared to be a hindrance for the students.

Keywords: multimodality; science education; design for learning; signs of learning; linguistically diverse classrooms

1. Introduction

In science classrooms, as in other disciplines, students need to use the language of the discipline, which becomes increasingly specialized during school years [1,2]. The language demands of science include lexicogrammatical and discipline-specific literacy challenges [3,4], such as dense nominal phrases including nominalizations. Thereto, meaning-making in science is dependent on the integration of semiotic resources in different semiotic modes (speech, image, discipline specific symbols, etc.), due to the character of the disciplinary content, which deals with, for instance, abstract phenomena or phenomena too big or small to be directly perceived through our senses. Therefore, when making meaning in science, besides written and spoken language, semiotic resources such as various graphs, diagrams, and concrete models are used [5,6]. The multimodal character of the discipline can be a challenge for students, since they need to integrate and alternate between a multitude of semiotic resources, which are used for specific aspects of the content, with each resource having its own explanatory, or meaning-making, potential for a science phenomenon. Hence, to be able to promote learning, teachers in science need to be aware of the discipline specific language—in a broad, multimodal, sense—and the potential challenges that come with it. Furthermore, they need to find ways of encouraging students to use this language. In this article, ‘semiotic modes’ refer to systems of meaning making, such as speech and gesture, while ‘semiotic resources’ refer to specific choices within these modes, such as specific lexicogrammatical choices or a specific image or gesture.
Building on the fact that human interaction is inherently multimodal [7,8], researchers in the area of second language learners have promoted teaching practices where different semiotic modes (e.g., speech, gesture, image) are used together, to achieve redundancy (cf. ‘message abundance’, [9]). This is viewed as a way to facilitate the students’ understanding and development of the verbal language (spoken and written) [10,11] in particular when making meaning about complex or abstract phenomena. Research suggests that such practices may be beneficial for all students, but especially for those learning the language of instruction and content in parallel [9,12]. Thereto, mainly focusing on the verbal language demands of science (speech and writing), several studies have shown how science teachers in linguistically diverse classes (for a definition, see Materials and Methods) can increase the students’ participation and learning opportunities by explicitly unpacking the language demands and by encouraging the students to express themselves scientifically [13–16]. Furthermore, research has proven that it is important that teachers in linguistically diverse classes tune into the students’ prior content knowledge including their level and use of scientific language [15,17,18]. Hence, in science teaching and learning, and in particular for students learning the language of instruction and subject content in parallel, teachers need to have a dual focus on multimodal aspects of meaning making in their subjects. On the one hand, students can be supported in their meaning making by giving opportunities to make meaning through multiple resources in various modes. On the other hand, teachers need to support students in regard to the specific multimodal characteristics of science discourse, which can be challenging for all students.

Several studies also reveal how the students’ multilingualism can become important resources for learning in science [19–25]. Some studies have combined a focus on the students’ multilingualism and multimodal aspects of the interaction [26–30]. However, few studies have investigated multimodal teaching and learning in linguistically diverse classrooms where students are educated in their second language without having their mother tongues as resources for learning. The lack of multimodal studies focusing on second language learners can be explained by the fact that in traditional second language education, semiotic resources other than verbal language have been seen as support for overcoming language barriers and to support students’ language development and not as central aspects of a discipline specific language [31]. Also, previous research has focused either on multimodality in content area classrooms or on how linguistic challenges could be supported by other semiotic modes than written and spoken verbal language. In this study, we combine these two perspectives, which means that we view teachers’ cognizant, multimodal teaching and learning design as a potential for promoting both content mastery and language development for students. Grapin [31] (p. 183) claims that the combination of the two perspectives in classroom practices may “offer affordances for all students to represent concepts more effectively and to engage in the type of visual representation that is valued in disciplines such as science”. This is especially important in linguistically diverse classrooms, such as the one in the present case study.

Even though multimodal perspectives still are relatively scarce in research concerning second language students’ learning in science, there are examples of such studies. Zhang [32] shows how a teacher’s multimodal communication in a sixth-grade sheltered classroom only provided limited support for the students’ knowledge building, something which was partly explained by the fact that the classroom communication “proceeded as one way regardless of the incorporation of multimodal communicative modes” [32] (p. 25). Siry and Gorges [29] describe how a girl in a linguistically diverse Kindergarten class uses gestures, facial expressions, body movements, different verbal languages and drawings as assets when expressing her understanding of sound. Ünsal, Jakobson, Wickman and Molander [33] show how a teacher supported the science learning of emergent bilinguals in a linguistically diverse grade 3 classroom. With the help of physical artefacts, the students were able to talk about their observations, but also understand the teacher’s unfamiliar scientific words and relate them to what they had experienced. The present study is based on data collected in a grade 8 physics classroom within a larger project, where we also
visited a year 5 linguistically diverse physics classroom. Jakobson and Axelsson [17] reveal how the teacher in the year 5 classroom builds a kind of web by making links between multiple resources, thus giving the students opportunities to link the content to earlier experiences and thereby to build science knowledge. Uddling [16] shows how the same teacher uses images and concrete objects to unpack textbooks texts, and how her explanations of seasons were gradually built up through a number of multimodal orchestrations, that is to say combinations of resources in different semiotic modes that form an entity. However, Jakobson and colleagues [12] reveal on the one hand how the multimodal interaction in the same science classroom offered the students increased opportunities to understand and to express the subject content through different semiotic resources. On the other hand, as not all of the semiotic resources appeared to increase students’ meaning making, one pedagogic implication from that study is that teachers need to be aware of their own use of different semiotic resources as well as the ways in which they create opportunities for students to make meaning of the science content through different resources. Most of the above-mentioned studies reveal that the use of different semiotic resources offers the students increased learning opportunities when they are learning the language of instruction in parallel with subject content [16,17,29,33]. Some of the studies also reveal hindrances for learning, for example when the teachers appeared not to use semiotic resources in a thoughtful way [12,32]. In the above-mentioned studies, the use of other modes than speech and writing was not only seen as a way of supporting verbal language development (cf. [31]), but also as a means for science learning and opportunities to participate in the multimodal interaction typical for science classrooms. A multimodal lens, however, can also shed light on the unique affordances and limitations of verbal language (cf. ‘semiotic affordance’, [7]) in relation to other semiotic modes.

The content area in focus for the teaching and learning activities that the present study builds upon is ‘sound’, and more specifically the wave model and the concepts frequency and amplitude. Previous research has shown challenges for students in this content area, for example students’ understanding of the central concepts of sound, such as sound waves, vibrations, and transmission of sound. One proposed explanation for the challenges is that students appear to understand sound as something material (e.g., [34]). In their intervention study, however, West and Wallin [35] showed how students can develop a scientific understanding of sound concepts by letting them experience these concepts by their senses, for instance how sounds of different frequencies sound. To our knowledge, there is a lack of language based observational studies performed in linguistically diverse classrooms where teachers support students—and where students support each other—to express their knowledge of sound in disciplinary language by use of different semiotic resources. Thereto, Seah and Silver [15] (p. 2455) emphasize that more research is needed on how teachers address the language demands of specific topics in science education, which is also focused on in the present study. In Sweden, where this study is set, around 25 per cent of the students in year 1 to 9 were born abroad or have two parents born outside of Sweden [36]. As a consequence, many Swedish classrooms are linguistically diverse.

The aims of our study are (i) to examine the teacher’s design of teaching and learning activities related to the wave model and the concepts frequency and amplitude in a secondary physics classroom where several students are second language learners, and (ii), to examine how the students through different resources elaborate on and interact about this physics content.

2. Theory

The point of departure for the study is that multimodality is inherent in all social interaction [7,8]. Therefore, our overarching theoretical stance is multimodal perspectives of social semiotics [7,8]. Social semiotics theory emphasizes the social aspects of human interaction, where the individuals are seen as sign makers when making choices among available semiotic resources in different semiotic modes, such as speech, gesture, writing, and image. Furthermore, all resources for meaning making are considered equally im-
portant, regardless of mode. Also, the choice of resource for meaning-making is viewed as a result of social, cultural, and situational factors, including participants and available semiotic modes and resources. A central concept in social semiotic perspectives of multimodality, and for our analyses, is the notion of affordance [8,37], here defined as the potential for meaning-making, or potentials and limitations of the resources used [8]. This term is often associated with ‘modal affordance’ [7,8], where, for instance, images are described as particularly apt for showing spatial properties while verbal language is described as particularly functional for reasoning about, e.g., cause and consequence. However, in any communicative situation, the specific choice of wordings, image, gesture, and the like, have different affordances depending on, for instance, content, culturally developed practices, and the participants involved. The choices made in a learning situation can also be discussed in terms of pedagogical affordance [38], as specific choices can function more or less well for a particular content and a particular student group.

From the sign making perspective central for multimodal perspectives of social semiotics, interaction can be viewed as a form of design [7] (p. 73). Such a design perspective is key in the theoretical field ‘designs for learning’ (DFL) [39,40] which is the basis for the analytical framework used in the present study. According to DFL, teachers’ choices in a teaching and learning unit are described in terms of designs for learning, while, in a similar vein, students’ choices in learning can be described in terms of designs in learning [39,40]. The choices can be planned, for instance when a teacher chooses to let students perform hands-on investigations with everyday artefacts, or when a student chooses to include a visual diagram in a text in physics. They can also be more or less unplanned, for instance when a teacher makes certain gestures without having planned to do so beforehand, or when using analogies that come to her mind as a way of concretizing abstract content. When interacting about subject content, representations of content are then transformed (within the same semiotic mode) and transduced (from one mode to another) [40]. Examples are when students convert the teacher’s written whiteboard notes into their own notebooks (transformation from writing into writing) or when students describe in words and image an experiment that they have just performed (transduction from action into writing and image). In that sense, learning can be understood as a “process of interpretation and sign production” [41] (p. 12) where learning is seen as “an increased capacity to use signs and engage meaningfully in different situations” [41] (p. 12). A central concept, then, is ‘signs of learning’, which is understood as a manifest change in students’ sign making [40,41]. One example is if a student who at one point has used a physics term or a visual model in an inadequate way, later does it in an adequate way according to the context. However, we want to point out that one cannot be sure that learning has actually taken place just because an adequate sign is used. Therefore, one can only note signs of learning in a learning process but not learning as such. Within DFL, the Learning Design Sequence Model has been developed. Figure 1 shows a recent version of the model, which can be used for longer (e.g., one lesson, or a series of lessons) teaching and learning and learning activities, or for shorter sequences, such as an activity within a lesson. The model, which is described in the following, is utilized in the present study to analyze the teachers’ design for learning over a number of lessons.

According to the Learning Design Sequence Model, a teacher’s overall design of teaching and learning activities relates to, for example, curriculum documents and institutional norms and regulations, such as school norms at a country level or more local norms developed at a specific school or in a specific classroom. These norms can concern, for instance, formal or informal rules regarding who is allowed to speak when, or whether students are encouraged to use all of their linguistic resources in class. The teacher also has a purpose with the planned activities, such as developing the students’ experimental skills or their knowledge about specific content. Furthermore, different resources (semiotic resources and different artefacts) are available depending on the classroom design, and the teacher decides what resources will be used. Based on these premises (framing), the teacher introduces the activities, or in other words “sets the scene” (setting). During the primary
transformation cycle, the students engage in different activities using available resources, transforming or transducing (‘transducting’ in Selander [40], incl. the model in Figure 1) content through representations in different modes. The primary transformation cycle can result in a representation (e.g., a written or spoken text) meant to communicate the students’ knowledge to others, for instance the teacher, classmates or someone outside of the school context. During the secondary transformation cycle, this representation and the learning activities during the first transformation cycle are in focus for meta-reflections between the teacher and the students. Throughout the teaching and learning sequence, the teacher and the students position themselves and each other in different ways. The teacher, for instance, can position the students as either capable or not capable of taking responsibility for their learning. Also, the model presumes that the teacher continuously assesses students’ ongoing learning process. An important aspect in the theory designs for learning is ‘cultures of recognition’, that is to say, what counts as valid knowledge in assessments. The model can be seen as a kind of ideal as, for instance, not all teachers and students engage in meta-reflective activities (secondary transformation cycle).

**Figure 1.** Learning Design Sequence Model (from Selander [40], Figure 1.3., p. 4, reprinted with permission from the author; Copyright: Staffan Selander).

3. Materials and Methods

The present study is part of a larger research project, *Multilingual students’ meaning-making in the school subjects biology and physics*, financed by the Swedish Research Council (Reference number: 2013-42867-99966-13). The data used in this case study were collected when we followed the regular teaching and learning activities in one linguistically diverse mixed gender grade 8 physics classroom (students aged 14–15 years) in a lower secondary school situated in a suburb outside a large Swedish city. In this article, “linguistically diverse classrooms” refer to classes where (i) students and teachers may have different mother tongues, (ii) several students have another mother tongue than the language of instruction, and thus, (iii) the classes comprise students with various mother tongues and varying levels of command in the language of instruction. The suburb in question has a large population of citizens with migrant background. Hence, a majority of the students in this school are multilingual, using two or more languages at home, and several of the students are educated in their second language. The classroom that was visited had 22 students, out of which 19 students agreed to participate in the study. Sixteen of them were multilingual, four of which were newly arrived (up to four years in Swedish schools)
and two students had less than six years in Swedish schools. Therefore, the class comprises students with varying levels of command in the language of instruction which was also seen during our classroom observations. The participating teacher was an experienced teacher, qualified for teaching biology, chemistry and physics in grades 4–9 and for science studies and biology in upper secondary school. In an interview [16], he said that he identifies himself as having a language focus in science instruction, not least depending on the fact that he had taken part of in-service courses about genre pedagogy (cf., [42]). He also said he was used to teaching in linguistically diverse classrooms, and that he therefore explained many words and thought a lot of how he expressed himself in the classroom. Furthermore, he said that he planned activities that he believed would encourage the students to use and develop the language of instruction (Swedish).

The collected data consists of video and audio recordings, digital photographs and collected texts (such as the textbook text and student texts). One video camera was placed at the back of the classroom, and it followed the teacher. The students were to some extent visible to the camera when interacting with the teacher. To capture students’ spoken interaction with each other, five audio recorders were placed on student desks. The overall project adheres to the ethical principles outlined by the Swedish Research Council [43], regarding the requirements related to information, consent, anonymity, and the right to withdraw from the project. All participants have been assigned new names, to ensure their anonymity.

In our analyses, we use data from the first four out of nine lessons (each lesson appr. 70 min long) focusing on the wave model and the description and explanation of sound. More precisely, we focus on the sequences that deal with the concepts ‘frequency’ and ‘amplitude’ (frequency concerns the distance between sound waves, which has consequences for the pitch of a sound, with high a frequency resulting in a high pitch; amplitude concerns the height of the sound waves, which has consequences for the loudness of sounds, with a high amplitude resulting in a loud sound).

To start with, the video data was subject to transcriptions of the spoken interaction along with comments on gestures, bodily action and resources used to interact about the content, such as artefacts used in hands-on activities, as well as drawings and writing on the whiteboard. Our first aim was to examine the teacher’s overall design for learning. This was done by utilizing the Learning Design Sequence Model (Figure 1), which was described in detail in the Theory section. In this study, we utilize the model for an overall description of the first four out of nine lessons that dealt with sound during our data collection.

Our second aim was to examine how the students through different resources elaborate on and interact about the physics content. Here, we are especially interested in examining students’ interaction over the teaching and learning period to identify signs of learning regarding their ways of describing and explaining the content in adequate ways and in accordance with the discourse of science. To identify such signs of learning, we made fine-grained analyses of students’ texts and their interaction with the teacher or with each other. Due to the characteristics of the collected data, we were able to analyze mainly spoken interaction, but at times, the video-camera captured students during their interaction. In such cases, other modes, such as gestures, were integrated in the analysis. These data were further analyzed according to the model in Figure 2 regarding lexical choices, and in a similar vein for other modes than speech or writing. This analysis concerned how students represent sound in different semiotic modes and combinations of them in multimodal ensembles. Sequences of classroom interaction (whole class and small group discussions) and student texts focusing on frequency or amplitude were picked out for the analysis.

Signs of learning were identified as instances when students changed their ways of describing or explaining sounds, for example from being inadequate or expressed through everyday language or non-scientific images at one point, to being adequate and expressed more in line with the disciplinary discourse through lexical choices or the use of other resources such as diagrams in line with those used in science. The examples used in the article were translated from Swedish into English with an aim to preserve the lexical choices.
made, sometimes resulting in non-idiomatic English. In the excerpts, minor grammatical errors were corrected when they could not be translated into equivalent English errors, or when they were not relevant for the analysis.

<table>
<thead>
<tr>
<th>Everyday discourse</th>
<th>Disciplinary discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mimic sound</td>
<td>Relate to everyday experiences</td>
</tr>
<tr>
<td>“rrr” (with a dark voice)</td>
<td>“sounds like a cowbell”</td>
</tr>
</tbody>
</table>

**Figure 2.** Verbal choices from everyday discourse to disciplinary discourse concerning sound (based on Uddling and Danielsson [44]).

### 4. Results

In the following, we begin with relating to our first aim by presenting the results from the analysis of the teacher’s design for learning, based on the Learning Design Sequence Model. Thereafter, we present the results in regard to our second aim. In that section, we give examples of students’ signs of learning based on three student groups’ designs in learning.

#### 4.1. Overall Design of the Teaching and Learning Activities

##### 4.1.1. Framing and Setting

As mentioned in the Methods section, the school in question has a large number of multilingual students learning the language of instruction in parallel with learning subject content.

The teacher’s overall design resulted in a classroom practice where students participated in various activities such as small group and whole class discussions, and hands-on activities involving everyday artefacts. The teacher, who had been teaching the class for over a year and a half when we visited them, commented to us that he had placed the students in the classroom based on his experiences about what students would “work well together” (his words). Thus, in pair work and work in small groups, the students knew each other and were used to working together. In the classroom activities, a variety of semiotic modes were used, such as speech, writing, image, and gestures. Apart from that, in his overview of content and when interacting with the students during their activities in small groups, the teacher himself to a great extent combined speech with resources such as gestures and bodily action, which promoted redundancy when interacting about the science content. The students’ use of other languages than Swedish was neither explicitly encouraged by the teacher nor discouraged, which would be typical for educational settings characterized by one-language-only norms (cf. [45]).

The unit of sound connects to a stated goal in the Swedish curriculum document for science education, namely that “[t]eaching should contribute to pupils developing familiarity with the concepts, models and theories of physics” [46]. At the beginning of each lesson, the teacher had written down the specific goals of the lesson on the whiteboard, and as an introduction he commented on them. A recurring goal was for the students to develop their ability to use “physics words”, and the teacher also made explicit that the correct use of scientific language in descriptions and explanations would render high
grades. He told the students that he wanted them to “think like scientists”, and that one important aspect of this was to “use physics words”.

As a starting point (setting) for the unit about sound, the students were given a list of central concepts for the content area. The list consisted both of subject specific terms such as sound waves, infrasound, frequency and Hertz, and everyday words such as loud/soft tones, hearing damage, and sound.

4.1.2. Primary Transformation Unit

During the four lessons about sound, the teaching and learning activities were designed to gradually put greater demands on the students, from engaging in activities building on everyday experiences and concrete investigations with everyday artefacts, to later using the wave model and physics concepts to explain what they had experienced through their senses. In parallel, the teacher himself gradually introduced and used resources typical for the science discourse, for example terminology such as frequency, and diagrams representing the wave model. The students were expected to do likewise.

During the first lesson, the students indicated their previous knowledge about the concepts and everyday words in the list provided by the teacher by marking each of them either as “can explain”, “understand” or “don’t know at all”, and they did this in pairs, using mini-whiteboards. Thereafter the teacher demonstrated that sound transmission requires a medium, in this case air, showing a bell jar with a ringing bell, then creating a vacuum inside of it to prove that no sound could be heard. The following two lessons, the students in pairs or small groups performed investigations focusing on sound, using everyday artefacts, for instance to make their own can telephones and to note how the sounds differed when they blew air into bottles filled with different amounts of water. Based on these hands-on activities, the students transformed and transduced the content, for example, from action into spoken small group-discussions and then into multimodal texts in their notebooks. When introducing the hands-on activities, the teacher instructed the students to listen carefully and then to describe the different sounds, and to write down the results from their investigations in their notebooks. As a point of departure for the descriptions of sounds, he had written the adjectives ‘loud/soft’, ‘bright/dark’, and ‘high/low’ on the whiteboard. When the students had finished their investigations during the third lesson, the teacher introduced the wave model as a scientific explanation of sound transmission and different sound qualities. This introduction was carefully orchestrated multimodally: the teacher made a drawing on the whiteboard, at the same time commenting on it verbally. He then turned to the students and staged the model with his own body, moving sideways combined with gestures in a wave manner to visualize the compression and rarefaction of particles (see Figure 3). Further, he wrote down subject specific terminology such as ‘frequency’, ‘amplitude’, and ‘Hertz’ on the whiteboard. When explaining these terms, he combined his words with changes of his voice to illustrate, for instance, high and low frequency. In his overviews of sound waves, the teacher repeatedly used the term frequency while more seldom mentioning amplitude.

At the start of the fourth lesson, the teacher asked the students to, in pairs or groups of three, discuss and on their mini-whiteboards write down an answer to the question “What does sound look like?”. The reason for this formulation of the task was that he wanted the students to refer to the wave model that he had presented visually the previous lesson, though he did not make this clear until after the activity. He then made a follow-up in whole-class, followed by a short repetition of the wave model, again through multimodal orchestration (writing, image, gesture, bodily action, and voice quality), though somewhat more briefly than his introduction during the previous lesson. As a next step, he introduced a worksheet (Figure 4) for the students to work with in small groups.
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Figure 3. Introducing the wave model through multimodal orchestration, lesson 3 (from Uddling and Danielsson [44]). The whiteboard notes include everyday language like wave crest (vågtopp), abbreviations like Hz, and short definitions of terminology, such as “frequency is the number of wave crests transported per second”.

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Figure 4. Details from the worksheet used during lesson 4 (translations to the right).

During that activity, the students discussed and made written responses to the assignments in the worksheet, where they were asked to describe the sounds that different sound waves might correspond to, and to give examples of where one might find that particular sound (see Figure 4).

Next, the students were asked to create group texts to explain one of the investigations that they had performed the previous lesson. The teacher gave no further instructions about how to formulate the texts apart from telling the students that they were supposed to use the wave model and “physics words”. The students discussed in their groups how to explain the investigations and how to formulate the explanation. The final activity of the lesson was a follow-up of this writing activity.

Each lesson, the students were engaged in a number of activities. In whole-class, they took part in the teacher’s highly multimodal expositions comprising, e.g., speech, gestures, bodily action, and voice quality, with the students contributing with their own ideas and questions. In small-groups, they performed hands-on activities, discussed their ideas about content, worked with pre-fabricated worksheets, and created their own texts. During these activities, the teacher circulated among the groups, listening to the students’ discussions and supporting them when needed, again using a multiplicity of resources in a multimodal orchestration, including images, spoken words, and gestures (also see Danielsson [47]). We also noted that the students themselves transformed and re-used resources that the teacher had used, such as his wordings, gestures, voice quality and the like. Throughout the activities, the teacher used students’ questions and comments about the content for assessment, though not always by giving comments in terms of right and wrong. Instead, he often returned to previously introduced aspects of the content, and interacted through multiple modes in parallel.
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4.1.3. Secondary Transformation Unit

We regard the final group texts that the students created during the fourth lesson to explain previous investigations as the representation to reflect upon. During the secondary transformation unit, during the follow-up of the writing activity, the students read their texts aloud in whole-class and the teacher commented on both the content and language, also asking other students to make comments. (These group texts were analyzed in regard to signs of learning in Uddling and Danielsson [44], and they will not be further commented on in this article).

Throughout the whole of the teaching and learning unit, the teacher positioned the students as capable of taking responsibility for their learning process, by giving them gradually more demanding tasks. For instance, at the beginning of the series of lessons, the students had concrete experiences of sound that they were supposed to describe through everyday language. Later they were expected to explain these experiences through more scientifically adequate choices (also see Section 4.1.2 Primary transformation unit). The students, on their hand, positioned themselves as interested and capable students, for instance by spending a lot of effort and time on discussing the content and posing relevant questions to each other and to the teacher and by supporting each other during the different assignments.

4.2. Signs of Learning

At the beginning of the theme ‘sound’, many students either said in the class, or indicated in the list of concepts, that they did not understand, or could not explain, the terms frequency and amplitude. Furthermore, the way that they talked about, for example “bright” or “dark” sounds, revealed that they did not fully grasp these words when used for sound. However, later, they showed signs of learning, for instance by using scientific terminology in adequate ways. During the fourth lesson, which is focused on in this section, signs of learning could be detected both in students’ group discussions and in their group texts. During this lesson they themselves were supposed to use the wave model and concepts like frequency in their interaction about sound. In the following, we present examples of signs of learning in three student groups.

A group consisting of Dannah, Jowan, Sanna, and Tim worked together with the assignments in the worksheet (Dannah was not part of the group discussion from the beginning but joined later). They then talked about how to understand the first wave in the worksheet (Figure 4) and what frequency is. By referring to the teacher’s verbal explanation and notes on the whiteboard (Figure 5) just before their group work started, Jowan, on the advice of Sanna, defined frequency as the number of wave crests per second.

Jowan also counted the number of wave crests in another sound wave depicted in the worksheet, noting that the frequency was four Hertz:

Tim: Frequency. Wait! I will finish writing this.

(silence)

Tim: Wait! I will finish writing this.

Sanna: It’s written there. It’s written there (refers to the notes on the board).

Jowan: It’s how many, what do you say, how many wave crests per second.

Hertz (refers to the whiteboard note).

Tim: That’s not Hertz.

Jowan: Number of waves per second.

Tim: Yes, but you don’t write four as you did before, do you?

Jowan: I will ask (teacher name) later.

In excerpt 1, Tim questioned Jowan’s claim that a certain amount of wave crests per second would correspond with the number of Hertz (which is the case). Thus, Tim was not sure if the number of wave crests per second corresponds to frequency. To make sure he was right, Jowan then asked the teacher, who confirmed that Jowan had measured Hertz correctly, which Tim then also confirmed:

Jowan: If there are three waves per second, do you write three Hertz? Do you?

Teacher: Mm (confirms).
Sanna: Wow.

Tim: You were right.

Jowan: I was right.

Hence, by using visual depictions of sound waves, Tim and Jowan confirmed with the teacher how to measure Hertz in the depicted sound waves. The image of the wave model, and the fact that the teacher earlier had modelled a way to explain dark and bright sound by counting Hertz (i.e., waves in the visual model) became resources for the students to express the content in accordance with the discourse of science. However, when the group thereafter compared the first and second sound waves in the worksheet, it was obvious that the vague and metaphoric adjectives (high/low) that the teacher (as well as the instructions of the worksheet) had asked them to relate to in their descriptions of sounds, were not helpful. Instead, the students used the term frequency, which they had earlier defined, in an adequate way:

Tim: This one is brighter than the first one. Not lower.

Jowan: Yes, it’s lower. Because, check this out! It’s not as high. Brighter and darker. What should we write?

Sanna: It has a higher frequency or . . .

Jowan: It has . . .

Sanna: It is higher.

Jowan: It has a higher frequency. I will write “It has a higher frequency than, than . . . number one” (writes)

As is shown in the excerpt, to avoid the imprecise adjectives “high/low”, Sanna suggested “higher frequency”, hence, without a noun, which Jowan confirmed. This lexical choice, instead of just the adjective “high”, shows how a subject specific language enables precision and increased consensus among the students. The term frequency also became functional for comparisons between depictions of different sound waves. Furthermore, this term in itself contains an explanation to why a sound is dark or bright, since the frequency number corresponds to the number of wave crests per second. Just like the teacher had done, the students also used voice quality to exemplify different sounds, for example when Jowan exemplified low frequency by the sound of a dark voice: “it sounds like this: uuuuh (dark voice). A zombie (laughs): Uuuh. Like an ordinary person when you are tired in the morning”.

Later, when creating their group text to explain one of the previously performed investigations of sound by using “the model of sound” and “physics words”, Dannah joined the group. Tim then asked his group mates how many Hertz they should write, commenting that they should have “many Hertz”, since the sound that they were going to describe was a bright sound. Then Dannah asked “Who is Hertz?”, revealing that she did not know that Hertz is not only a name (the teacher had mentioned that during the previous lesson), but a concept they could use when describing sounds. It surprised Tim that Dannah had not grasped this:

Tim: Okay. How many Hertz should we have? Since it’s bright we need many Hertz.

Dannah: Who is Hertz?

Tim: Don’t you know what Hertz is?
Dannah: No.

Tim: Okay. How many wave crests per second. Do you get that?

(inaudible)

Sanna: Hertz is, you measure.

(inaudible)

Sanna: Hertz is how many wave crests per second.

Tim: Here there is room for five wave crests per second (counts waves in an image of a sound wave in his notebook). Then it becomes five Hertz. Do you get that?

Dannah: Okay! It becomes like this . . . One, two, three, four. Then it’s four (draws an image)

(excerpt 4, lesson 4)

Hence, Tim and Sanna explained the concept Hertz to Dannah as the number of wave crests per second and that you need to measure (count) them. Tim also showed how to decide the frequency with the help of a visual depiction of a sound wave. During the previous lesson he had transformed the teacher’s multimodal text at the whiteboard (see Figure 3) into his notebook (Figure 6) and now he used that image to illustrate how to decide the frequency from a visual depiction of sound waves.

Figure 6. Tim’s notes transformed into his notebook from the teacher’s whiteboard notes when presenting the wave model, lesson 3 (translations to the right).

Tim’s counting of wave crests in the image obviously helped Dannah, who then drew sound waves, at the same time counting them, concluding that her image corresponded to four (Hertz). Hence, the use of image functioned as a learning resource for Dannah, due to its affordance to visualize something abstract, in this case the concept Hertz. This example shows Dannah’s signs of learning, where it was first obvious that she did not know the concept Hertz, but later showed how a sound wave can be described with the use of Hertz. Also, this is an example of how students in the class supported each other’s learning process.

Further, when the teacher later made a follow-up of the activity in the whole class, Dannah again showed that she had learnt the meaning of Hertz. When the teacher asked...
the class what Hertz is, she responded that it was “like how many wave crests that pass
during a second.” The group then continued to discuss how many Hertz they should write
when describing the bright sound that they had experienced in the previous investigation.
Dannah then asked the teacher whether eight Hertz, as was suggested by the group, was a
dark sound rather than a bright one:

Dannah: Eight Hertz. Isn’t that dark?
Teacher: It depends on whether you talk like this (with a dark voice) or if you
talk like this (with a bright voice).
Dannah: Isn’t eight Hertz dark?
Teacher: When you get to twenty thousand, then it’s very bright.
Dannah: Yes, but you know the spoon (refers to a previous investigation). How
many Hertz do you think that is?

The teacher used his voice to illustrate a dark and a bright sound. However, he did
not sort out Dannah’s question whether eight Hertz was a dark sound, in spite of the fact
that a low frequency like that is inaudible for humans. Instead, Dannah asked how many
Hertz he thought that the sound of the spoon created in the previous investigation of sound.
Again, Dannah showed a sign of learning when she in her question revealed that she now
knew that frequency is measured with Hertz and that she was also quite sure that eight
Hertz does not correspond to a bright sound. By now having access to the concept of Hertz
she had increased opportunities to compare how dark or bright a sound is in a precise way.
Taken together, Tim’s and Dannah’s access to visual representations of the wave model and
their ability to communicate about the model through different semiotic resources, such as
images and precise terminology, increased their learning opportunities.

4.2.2. Height and Distance of Waves in Small Group Discussions:
Multimodal Orchestration

In the previous section we showed how a student group made use of the visual
representation of the wave model to count wave crests in order to decide the frequency of
sounds by using the concept Hertz. Another group, Kalene, Rana, Tanesha, and Widad,
also used the visual representation of the wave model as a resource for describing depicted
sound waves in the worksheet. When they were about to describe one of the sound waves,
Tanesha first said that she believed that a high frequency means a low sound instead of a
bright one. She then asked the teacher how frequency could relate to sounds:

Tanesha: Sound fre- or the frequency of sound, what difference does it make
for how the sound sounds?
Teacher: The frequency?
Tanesha: Yes.
/ . . . /
Teacher: Low frequency and the brighter, the higher (inaudible) the denser
the wave crests. And you remember the squeaking sound (squeaks), it
was really unbearable at times (refers to sounds that were played from
the computer during a previous lesson)
Tanesha: Mm.
Teacher: So the denser the wave crests, the, ehun, what to say, the higher
sound or brighter sound.
Tanesha: Okay.

(excerpt 6, lesson 4)

Hence, the teacher exemplified a bright sound with his voice and explained that the denser the wave crests are, the brighter sound. A little bit later Tanesha showed signs of learning when she in her group, with the help of the depicted wave model, described the difference between dark/bright and soft/loud sounds with words like “distance” and “height”:

Rana (to Tanesha): Tell us again! I don’t get it.

Tanesha: A high tone has shorter distances than a low tone.

Widad: Mm.

Tanesha: It has more distance.

Widad: Yes

Tanesha: And then when it is soft or loud then it’s the height of the crests that you measure. So a loud tone has higher waves than a soft tone.

Widad: Yes, that’s what he said.

(excerpt 7, lesson 4)

The words “distance” and “height” in reference to the visual representations became useful lexical resources that helped Tanesha to explain the physics content efficiently, and to compare the different frequencies depicted in the images of sound waves in the worksheet (distance between waves) but also different amplitudes (height of waves). When Tanesha combined her understanding of the visual representations of the wave model with the use of lexical resources she thereto communicated about bright/dark and soft/loud sounds in line with the precise and dense language of the discipline.

Tanesha also used the image of the wave model when she explained how density (i.e., the distance between particles in sound waves) determines how dark or bright a sound is. Again, the teacher’s illustration of high and low pitch by the use of the voice was taken up by the students:

Teacher: It’s not bright like it’s cheeping “wiwi” (makes bright, cheeping, sound) [Rana: no] but “oooo” (makes dark sound)

Kalene: Then there would have been loads here (points at a depicted sound wave)

Tanesha: Then it would have been dense

Teacher: It would have been denser then?

Students: Yes

Teacher: Okay, so it’s not that dense then

Students: No

Teacher: If you compare it with the others then, how, how, with this for example (points at a sound wave in the worksheet showing high frequency).

Rana: That one is bright, it’s like iii (with a bright voice).

Teacher: Because . . .

Rana: Then it’s dense.
Tanasha: Because it’s a compression.
Rana: Yes.
Tanessa: They are together like this (moving her arms towards each other).
Teacher: What is dense?
Rana: Molecules.
Tanessa: No, atoms.
Teacher: Yeah? (hesitant).
Tanessa: The waves (laughs).
Teacher: The waves are dense, yes.

(excerpt 8, lesson 4)

Excerpt 8 also reveals how Tanessa explained that it was the compression (a nominalization) that caused the bright sound. After a while, when the teacher returned to the group, Tanessa explained to him that a dark sound means that “it” is far apart. The teacher then asked her how she could see this (in the image) and asked her to specify what was far apart:
Tanessa: It’s dark.
Teacher: Dark? Yes. It’s dark. How can you see that Tanessa?
Tanessa: Because they’re far apart from each other.
Teacher: From what is it far apart?
Tanessa: Well the waves.
Teacher: The waves? Yes

(excerpt 9, lesson 4)

Excerpt 9 shows that Tanessa clarified her comment by saying that it was the waves that were far apart. Tanessa did not use the term frequency but showed that she had learned to express the physics content with the help of the wave model. The image(s) that illustrated the distance between the waves enabled her to express and explain the meaning of frequency.

Thereto, apart from using voice quality in a similar way as the teacher did (e.g., excerpt 8), the students also used similar gestures to that of the teacher when reasoning about frequency and amplitude. The image in Figure 7 shows one such example, illustrating how Kalene visualized high frequency by quickly moving the pen in her hand up and down.

4.2.3. Text Creation in Pairs: Explaining Frequency through Image and Writing

Our last example shows how a couple of students, Benito and Edin, show signs of learning in texts that they created to describe what signifies sounds of different frequencies, first at the beginning of the fourth lesson and then later during the same lesson. The first text was created during the first activity, when the students were asked to describe what sound “looks like”. The second text was their written response in the worksheet that they later worked with in small groups.

As a response to the first assignment, to describe what sound looks like, Benito and Edin made a multimodal text on their mini-whiteboard (Figure 8). They wrote a short description of what signifies different heights of the sound waves. Then they depicted two sound waves through a drawing, combined with labels. In both writing and image, they mixed up frequency with amplitude. In writing they related the height of waves to
darkness and brightness. Likewise, the drawings showed high and low waves with the labels “dark” and “bright”, respectively (Figure 8).

**Figure 7.** Kalene (to the right) visualizes high frequency with a gesture, quickly moving the pen in her hand up and down, lesson 4.

**Figure 8.** Benito and Edin describe what sound looks like, beginning of lesson 4 (translations to the right).

Sound looks like waves. The higher they are, the darker the tone, the lower they are, the brighter the tone. Sounds are created through atoms that bump into each other.

<table>
<thead>
<tr>
<th>Dark</th>
<th>Bright</th>
</tr>
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When the teacher made his follow-up of the activity, Benito and Edin were asked to show the class their images and they read aloud from their written texts. The teacher did not correct or comment on texts like theirs, in which sound was described inadequately. Instead, as mentioned, he made a short repetition of the wave model, drawing the model on the whiteboard and commenting on it through multimodal orchestration. Next, the
students worked in groups with the worksheet where they were asked to describe drawn representations of sound waves.

Edin and Benito worked together to respond to the tasks in the worksheet where they described the different representations of sound waves in regard to their height and density. In this text they adequately related the height of waves to loud or soft sounds and the density of the waves to frequency, combined with the adjectives dark and bright (Figure 9). Hence, by engaging in the different activities that the teacher had designed, Edin and Benito used the term frequency adequately at the end of the lesson and they also connected the visual representations of sound waves in the worksheet to different frequencies in adequate ways.

3. Figure number three has short wave troughs and short wave crests. Which gives a soft sound. The wave has a very low frequency, which gives a very low sound.

4. Figure number four has high wave crests and high wave troughs which give a loud sound. The wave has a very high frequency which gives a bright sound.

Figure 9. Edin's notebook describing sound waves in the worksheet, later lesson 4 (translation of two of the responses).
5. Summary and Discussion

With the present study, we sought to contribute to the research field related to multimodal teaching and learning in linguistically diverse science classrooms where several students are educated in their second language without having their mother tongues as resources for learning. We investigated the regular teaching and learning practices in a secondary physics classroom where the students worked with the area of sound, which previous research has identified as a challenging content area [34]. In the following, we discuss our main findings in regard to our two aims, namely to investigate on the one hand the teacher’s design for learning related to the wave model including the concepts of frequency and amplitude, and on the other hand the students’ design in learning and how they through different resources elaborated on and interacted about this physics content and how they in this process showed signs of learning in regard to content and the way content was expressed.

The teacher’s design for learning showed how he arranged for the students to take part in a variety of activities, including performing investigations, participating in whole-class and small-group discussions, as well as using and creating multimodal texts. In all of these activities, they were given opportunities to make meaning through a multitude of artefacts and semiotic resources, such as hands-on material, spoken and written language including both everyday language and subject specific terminology, as well as diagrams representing sound waves. Further, in his overviews of content and when interacting with the students in small groups or pairs, he, as a rule, communicated the content in multimodal orchestration, with resources such as gestures or voice quality illustrating or enhancing what was communicated through speech. In this way, he ensured a level of redundancy that could be especially beneficial for this student group where several students are educated in their second language [9]. As was shown in the results section, the teacher’s use of gestures and voice quality was also taken up by the students, which indicates that these choices functioned as a support for the students. However, the teacher did not explicitly talk about how different modes and specific resources contribute to expressing the content (cf. affordance).

In our analysis of the students’ design in learning, we found several examples of signs of learning, where we could note how the students gradually expressed the content adequately and in line with the disciplinary discourse, in this case through lexical choices or other resources relevant for the discourse of science. Further, the results indicate that students’ use of scientifically adequate language, for instance, precise terminology, increased their opportunities for interacting about the content in a more efficient and precise way, which in turn appeared to increase their learning. One example is shown in excerpt 3, where Sanna and Jowan use the precise “higher frequency” instead of just “high” or “brighter”. In this classroom, where students often worked in pairs or small groups, students frequently negotiated the physics content and language with each other. By doing so, their opportunities to learn the content and disciplinary language appeared to increase since they were eager to use adequate terminology and to support each other’s content learning (see, for example, excerpt 4). This is particularly noteworthy considering that several students were being educated in their second language.

In linguistically diverse classes, it can be challenging to establish a level of instruction that suits most students. In spite of this, throughout the whole of the teaching and learning unit, the teacher positioned all students as capable of taking responsibility for their learning process, by giving them gradually more demanding tasks, starting with concrete experiences that they were supposed to describe through everyday language, later being expected to formulate explanations through more scientifically adequate choices. The students, on their hand, positioned themselves as interested and capable students, for instance by spending a lot of effort and time on discussing the content and posing relevant questions to each other and to the teacher.

To sum up, in this study we have investigated multimodal teaching and learning in a linguistically diverse physics classroom where several students are educated in their
second language without having their mother tongues as resources for learning. We have also combined two perspectives where we on the one hand view multimodal interaction as potentially supportive for students (e.g., [9]), while on the other hand we view the multimodal characteristics of science discourse as potentially challenging for students (e.g., [5,6]). The teacher in our study focused on the demands of science in relation to physics words, terminology and the wave model, and he encouraged the students to use these semiotic resources in whole class interaction, group work and in their written texts. However, he never mentioned how the different semiotic resources made meaning, or how they are used in the discourse of science. Instead, it seems like the teacher himself mainly used other modes than speech and writing to create redundancy and to support the students’ learning of the science content and verbal language (cf. [9]). One example is his multimodal orchestration when introducing the wave model (Figure 3) where he combined speech, writing, and image with body movement, gestures and different voice quality.

This case study was performed in a linguistically diverse classroom. However, we believe that similar designs for learning would also be beneficial for more linguistically homogenous classrooms, where the students might be either native or non-native speakers of the language of instruction.

To our knowledge, the Learning Design Sequence Model has not as yet been used for analyzing interaction in science classrooms, and therefore the way we have analyzed our data in the present study is also a contribution to the research field of science education.

Further Research and Limitations

In the present study, we have mainly studied students’ signs of learning in group work. To a greater extent being able to follow individual students’ signs of learning during a teaching and learning sequence, we would have needed another setup with more detailed knowledge about students’ competence in the language of instruction and science knowledge in any language. As this was not the focus of the overall project, such data was not collected. This can be viewed as a limitation of the present study and could be one suggestion for further research that could add interesting knowledge to the research field.

Furthermore, it is not possible to make generalisations from the present study, since it is a case study collected in a specific context. However, even so, the results indicate that the teacher’s design for learning where the students engaged in a variety of activities involving a multitude of modes and resources became a support for the students to develop and enhance their content knowledge, including ways to make meaning about the content through the language of the discipline in a broad sense.

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