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Features and Functions of Scientific Language(s) in TIMSS 2011

Abstract

This study examines differences in language use in different scientific subjects by analysing all grade 8 science items from TIMSS 2011. Four meaning dimensions are identified as central for analysing what functions different linguistic features fulfil in scientific language. They concern the levels of Packing, Precision and Presentation of information, and the level of Personification in a text.

The results show that language use in TIMSS differs in some ways among the scientific subjects. Average physics language uses more words. Language use in biology shows higher Packing and lower Precision, while physics shows the opposite pattern. Although items are generally low in Personification, the language of physics has higher levels of Personification, especially compared to earth science. Language in chemistry often presents information in more complex ways. According to these results, the study appears to challenge the notion that there is a single scientific language.

INTRODUCTION

A scientific language is easily recognized, and not only on account of the subject or the technical terms used. It has some distinguishing linguistic features that, though they exist in more colloquial “every day” language, are more predominant in a scientific language. Examples of such linguistic features are a more extensive use of complex noun phrases with many modifiers, a specialized vocabulary and the use of the passive form and nominalizations that remove the agent and, subsequently, the need to use personal pronouns. Scientific language thus appears as abstract, objective and information-oriented (Schleppegrell, 2004; Veel, 1997; Wellington & Osborne, 2001). Instead of viewing these features as obstacles that complicate language use and thus obscure content, they can be regarded as an integral part of science that has evolved over several hundreds of years (Banks, 2005; Halliday & Webster, 2004). Halliday and Martin (1993) even go so far as to state: *The evolution of science was, we would maintain, the evolution of scientific grammar* (p. 12).

However, many studies of scientific language and summaries of such studies do not separate scientific languages into subjects, but rather refer to a general scientific language (e.g. Hatzinikita, Dimopoulos & Christidou, 2008; Schleppegrell, 2004; Veel, 1997; Wellington & Osborne, 2001), or analyse the language in one scientific subject without making comparisons to others (for a Swedish language school context e.g. Danielsson, 2010; Ekvall, 2011; Nygård Larsson, 2011). This study therefore investigates the notion that a single scientific language exists and examines possible differences in language use in various scientific subjects. The international Trends in International Mathematics and Science Study 2011 (TIMSS) (Mullis, Martin, Ruddock, O’Sullivan & Preuschoff, 2009) is produced by the International Association for the Evaluation of Educational Achievement (IEA), an independent international cooperative of national research institutions and governmental research agencies (IEA, 2011). Nearly 200 science items from the Swedish version of TIMSS 2011 are analysed as examples of language use in four different science subjects: biology, chemistry, earth science and physics.

There are several advantages to using an international large-scale study as the object of analysis. As items from different school subjects are included in the same test, they have a similar design, with both constructed-response questions and multiple-choice questions. The availability of solution frequencies and background information for the large number of participating students allows the results of the linguistic analysis of this study to be combined with future analyses of test performances by different groups of students. Potential also exists for future comparisons of how scientific languages vary geographically by using this study’s results and the results obtained from corresponding analyses of other languages used in TIMSS.

AIMS OF THE STUDY

Founded on a social semiotic perspective, this study investigates language use in the science items from the Swedish version of TIMSS 2011 grade 8 by using characteristic linguistic features of a scientific language and the functions such features have. The study suggests that there is no uniform scientific language, but rather that there are obvious differences in language use among the subjects in the field of science. Language use in biology, chemistry, earth science and physics may share common features, but the extent to which these features are used may differ substantially.

By analysing grade 8 science items in the Swedish version of TIMSS 2011, this study aims to answer the question:

What differences regarding the use of common linguistic features in scientific language are evident in the four subjects in TIMSS: biology, chemistry, earth science and physics?

The discussion explores how such differences can be understood relative to how the four subjects are portrayed in this type of test, while reflecting on these subjects’ characteristics for this age group.

PREVIOUS RESEARCH

Scientific language as a whole uses many different semiotic resources, such as oral or written language, images, diagrams, layout, and so on. This study focuses on written language. Below is an exploration of typical linguistic features of written language found to be relevant in earlier research for analysing science texts.

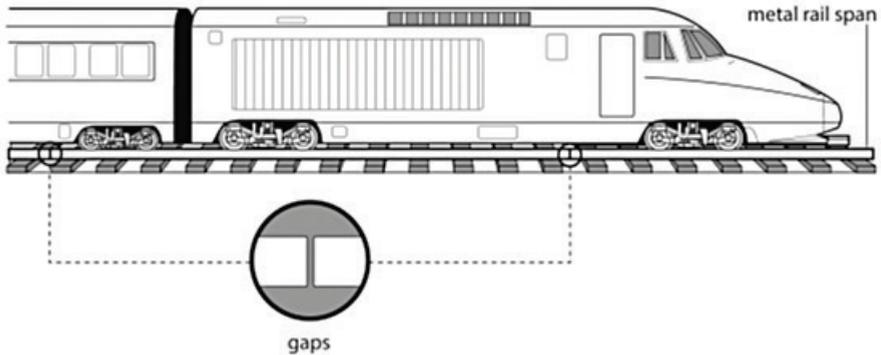
The suppression of agency is a common attribute in scientific language. It allows texts to be written without – or at least with fewer – personal pronouns, thus reducing the level of personalized connections within the text. This is often achieved through extensive use of passives. Passives allow the author to shift focus from objects or the people responsible for an action and to emphasise instead the phenomenon/process/result. Some studies show that although use of the passive voice makes a text seem more objective, it may also make the text alienating for most students, because they are not familiar with the way in which it is written (Fang, 2006; Wellington & Osborne, 2001). The *TIMSS 2011 Item Writing Guidelines* (Mullis & Martin, 2011) state that items are to be written in the active voice.

Use of abstractions is another way to reduce personification, i.e. to shift the focus from “the doers” to “what is done”. The level of abstraction in a text depends on several factors, but two related factors stand out as especially important: technicality and grammatical metaphor (Edling, 2006). Technicality is more than a set of terms; it is taxonomically related to technical terms, which organize reality in a different way than common sense does (Martin, 1993). Most technical terms are nouns (Martin, 1993), often created by noun compounding or expanded noun phrases with multiple modifiers (Schleppegrell, 2004). Such modifiers are mostly adverbs or adjectives that specify certain characteristics, thus enhancing the precision of the language. A grammatical metaphor refers to when one kind of grammatical structure replaces another. In science, nominalizations – i.e., turning adjectives or verbs into nouns – are a grammatical metaphor commonly used to express processes or qualities as entities, thus often hiding the agent (e.g. Graesser, McNamara & Kulikowich, 2011; Halliday & Martin, 1993; Hägerfelth, 2004; Schleppegrell, 2004; Veel, 1997; Wellington & Osborne, 2001). Scientific writing privileges nouns – especially extended and nominalized nouns – as they can present previously mentioned information as entities (Fang, 2005; Fang & Schleppegrell, 2008), thus increasing the packing of the information. Verbs and nouns can thus be regarded as complimentary, as dense language use (as in science) has more nouns and fewer verbs, and vice versa for less dense language (Graesser et al., 2011; Heimann Mühlenbock, 2013).

The item S032238 below (Example 1), taken from the English version of TIMSS 2011 (Foy, Arora & Stanco, 2013), exemplifies some of the linguistic choices regarding abstractions available to authors.

Response options A & B employ the verb *expand*, which – in a more abstract expression – could have been nominalized into *expansion*. That nominalization would have made it possible to create a sentence with hidden agency: *To allow for expansion of the tracks on hot days*, or even a shorter, more compact sentence: *To allow for expansion on hot days*. In response options C & D, the verbs *cool* and *vibrate* are nominalized into *cooling* and *vibration*. Response options A & B require a [grammatical] subject that expands, whereas the nominalizations in response options C & D can, if desired, function as the subject of a clause, thus removing the need for an agent. In the Swedish version, the corresponding verbs in all response options are nominalized (*utvidgning, avkyllning, vibrationer*).

The nominalized verbs in Example 1 can also be seen as technical terms, as there are other expressions using more colloquial language available in the Swedish language. Technical terms condense information, i.e. increase the packing of information, but the process of creating such terms often results in increased word length. The Swedish language has the ability to construct compound words of almost indefinite length, which in many other languages may require two or more words. An example from TIMSS is *Rate of Photosynthesis*, which translates to Swedish as *Fotosynteshastighet*. Such long words may be uncommon in everyday language, but might have been repeated many times in



Which of the following best explains why some railroad tracks are laid down with gaps between the metal rail spans?

- (A) To allow for the metal tracks to expand on hot days.
- (B) To allow for the metal tracks to expand on cold days.
- (C) To allow for cooling of the tracks by air in the gaps.
- (D) To allow for vibration of the tracks due to the train.

Example 1. Physics, item S032238 (Foy et al., 2013).

the context of school science and are likely to be more easily understood if the reader has encountered them several times before. Low-frequency words are an important limiting factor in text comprehension; more seldom used words tend to be longer (Graesser et al., 2011) and scientific texts written in the Scandinavian languages generally use more compound words and fewer nominalisations than the corresponding English texts (Ekvall, 2011). Therefore, word length can be used as a variable when analysing the reading demand of texts. However, using word length when analysing science texts can result in a tendency to underestimate the reading demand of texts in physics, as they have many short “concept words”, and to overestimate biology texts, as they often have long “naming words” (Wellington & Osborne, 2001).

Pronouns are less common in writing than in spoken language but are of importance regarding cohesion, as it can be difficult for a reader to link the pronoun to what or whom the pronoun is referring (Graesser et al., 2011). By using nominalizations and passive voice, scientific language generally avoids pronouns, and especially first person pronouns (Schlepppegrell, 2004). The use of personal pronouns can make a science text less alienating for students (Wellington & Osborne, 2001). When analysing communication between Swedish students working in groups with items from the international study PISA (OECD, n.d.), Serder and Jakobsson (2015) found that when fictional peers [represented by both proper names and personal pronouns] in the items used scientific language, the students positioned themselves away from the fictional peers, thereby also distancing themselves from the items.

Subordination is another linguistic feature that is often viewed as a complex way of presenting information, as it puts one clause within another in a hierarchical relationship, often indicated by connectives linking the clauses. However, subordinated clauses are of two different types. They can either function as [part of] a nominal group or they can depend on the main clause. Thus, subordinations can serve different functions and introduce different kinds of complexity (Schleppegrell, 2004). Many modern textbooks have removed connectives in order to improve readability (Wellington & Osborne, 2001), thus changing the way the information is presented.

The use of scientific language to display knowledge in an objective way creates lexically dense and logically structured language (Schleppegrell, 2004). Wellington and Osborne (2001) find the single use of readability tests of little value for evaluating science textbooks, as they do not measure lexical density. This implies that a measure of information load (i.e. how much information is packed into a text) should also be included when analysing texts used in school. Examples of such measures of information load include the *nominal ratio*: the number of nouns, prepositions and participles divided by the number of verbs, pronouns and adverbs (Einarsson, 1978) or the *lexical density*: the number of content words per non-embedded clause (Halliday & Matthiessen, 2004), where content words are nouns, verbs, adjectives and some adverbs.

As seen from this overview of earlier research, different linguistic features that are characteristic of scientific language serve to make the information in a text packed and precise, to downgrade personal relationships, and to have a more complex presentation of the information. Therefore, the linguistic features of a scientific language can be studied through the lenses of the functions they fulfil and the meanings they carry.

THEORETICAL FRAMEWORK

A theoretical framework that allows for the study of typical linguistic features of scientific language and for seeing what functions they fulfil in order to create and carry meaning is the social semiotic perspective as it has been developed in different arrays based on Systemic Functional Linguistics (SFL) (e.g. Christie, 2012; Coffin & Donohue, 2014; Halliday, 1978; Halliday & Hasan, 1989; Halliday & Matthiessen, 2004; van Leeuwen, 2008). In SFL, the fundamental property of language is considered its function to create and carry meaning. How language is used in certain contexts and the choices made are thus more important than the structural rules of a language. Three functional components of the semantic or meaning system, i.e. three meta-functions of a text, are considered: to express some content and establish a relationship with the reader/listener, while also having an identifiable structure. Here, 'text' means *language that is functional* in any medium of expression, e.g. a written or spoken text (Halliday & Hasan, 1989, p. 10). The first meta-function carries the so-called *ideational* meaning, through which the content of a text is expressed. The ideational meaning primarily concerns everything from everyday aspects to more technical and specialized aspects, often discussed in terms of processes and participants. However, scientific texts focus on processes, which are often reconstrued in turn as nominalizations, thus removing the agents of the processes (Schleppegrell, 2004). The second meta-function carries *interpersonal* meaning and expresses personal relationships in the text and with the reader/listener. It concerns attitudinal aspects and dichotomies such as subjective/objective and informal/formal. The third meta-function carries a *textual* meaning in order to express how the text is structured, concerning ways of organizing and presenting information, e.g. through different types of cohesive relations.

Central meaning dimensions

The functions fulfilled by different linguistic features that are characteristic of scientific language found in earlier research have been interpreted in this study in terms of the three meta-functions developed in SFL. *Packing* the information and making it more or less precise is interpreted as an aspect of the meta-function that carries ideational meaning, since it concerns how the content of a

text is expressed by more or less expanded noun groups, including nominalizations (e.g. Christie, 2012, pp. 14-15, 27). Van Leeuwen (2008, pp. 43, 63) discusses this in terms of the objectivation of processes by nominalization, and identification of participants by classifiers in nominal groups. The characteristic trait of scientific language to downgrade personal relationships is interpreted as an aspect of the meta-function that carries interpersonal meaning, since it concerns attitudinal aspects and dichotomies such as subjective/objective and informal/formal. Van Leeuwen (2008, p. 46) discusses personalization and impersonalization in terms of the existence or non-existence of personal or possessive pronouns in a text. The complexity in presenting the information is interpreted as an aspect of the meta-function that carries textual meaning and “helps organize the clause as a message, giving order to the ideational and interpersonal meanings” (Christie, 2012, p. 22). Consequently, *Packing*, *Precision*, *Personification*, and *Presentation* of information will be considered in this study as central meaning dimensions of scientific language.

SFL thus provides a solid framework to justify a selection of relevant linguistic features and what function they fulfil in order to express different types of meaning. The use of meta-functions also provides a way to raise results from an analysis of linguistic features in a text to a more comprehensive level. This implies that it is possible to study other types of linguistic features than those chosen in this study. In this vein, this framework will also support future comparisons between languages, because the three meta-functions may be expressed by more or less language-specific linguistic features.

DATA

The empirical data in this study consists of the 8th grade science items from the Swedish version of the international study TIMSS 2011. Although the subject of earth science is not taught in Swedish schools, the scientific content of TIMSS was found by the Swedish National Agency for Education to have almost complete coverage (96%) of the scientific elements in the Swedish science curricula in use at the time of the test (Skolverket, 2006). To avoid somewhat arbitrary reclassifications of earth science items into corresponding Swedish school subjects (i.e. biology, physics and geography), earth science is kept as a subject in this study. This choice also facilitates future comparative studies of differences in language use between countries, languages and similar international tests.

Rules were developed for when to merge items (i.e. for items requiring multiple answers or consisting of several parts) so that words in leading texts or diagrams above the core questions were counted only once. Using TIMSS categorizations, the remaining 197 items were divided into subjects: biology, chemistry, earth science and physics (Table 1).

Table 1. Item divisions and words per item and subject.

| | Total Number of items | Number of words per item | | |
|---------------|--------------------------|--------------------------|-----|-----|
| | | Average (SD)* | Min | Max |
| All subjects | 197 | 45.0 (28,7) | 8 | 170 |
| Biology | 69 | 43.4 (29,3) | 8 | 137 |
| Chemistry | 44 | 42.0 (28,8) | 10 | 170 |
| Earth Science | 35 | 40.7 (30,1) | 9 | 140 |
| Physics | 49 | 52.2 (26,0) | 13 | 114 |

* SD = Standard Deviation

METHOD

Data treatment

SFL provides a framework for conducting many different analyses of language use, such as a more detailed analysis of the nouns (participants) and verbs (processes) used in order to express ideational meaning; the appraisal system used to express interpersonal meaning, and theme-rheme patterns or lexical chains in order to express textual meaning. However, these features require a manual analysis.

To allow for an analysis of a material as expansive as the tasks of TIMSS 2011, a computer pre-processed database containing these items has been used. The database provided linguistic variables, such as part-of-speech (word-classes), and data such as word length and number of words (see Liberg & Forsbom, 2009; Uppsala University, 2008). Automated analyses of the characteristics of a text may be considered more reliable and objective than human ratings (Graesser et al., 2011) but they are also vulnerable to systematic errors when analysing special types of texts for which the program has not been trained. Some key features of the computer pre-processed database were thus manually checked to ensure that both parsing (splitting texts into component parts) and tagging (marking words into parts-of-speech) were correct. Some classifications in the computer pre-processed database were changed due to errors or inconsistencies, and to better match the purpose of this study. Examples include the creation of the new parts-of-speech variable “Descriptive Names,” and the separation of pronouns into subgroups and additional identifications (i.e. subordinate clauses, passive forms). As the variable “Proper Names” was reserved for names of people, places or countries, the variable “Descriptive Names” was created for letters and numbers that function as nouns or adjectives, e.g. [solution] A, 2. To prevent skewing of variables, numbers and months on the axis scales of diagrams have been excluded. As many response options are incomplete clauses and TIMSS – at least in the Swedish version – is not consistent with its use of capital letters and full stops, the number of words, rather than sentences, was chosen as the divisor to compensate for differences in text length between items. All variables (Table 2) are therefore divided by the number of words in the item (Table 1).

The four meaning dimensions

The four meaning dimensions, *Packing*, *Precision*, *Personification* and *Presentation*, are built up by different linguistic features that were available in the pre-processed database (Table 2). The number of words per item was also used as a standalone variable in the analysis (Table 1).

Table 2. Relations between analytical divisions of a text.

| Meta-function | Meaning dimension | Linguistic feature (per words in the item) |
|-----------------------|-------------------|--|
| Ideational meaning | Packing | Nouns + Long words |
| | Precision | Adjectives + Adverbs + Counting words + Descriptive names + Participles |
| Interpersonal meaning | Personification | (1 st , 2 nd , 3 rd Person) Pronouns + Proper names |
| Textual meaning | Presentation | Passives + Subordinate clauses |

The meaning dimension *Packing* consists of the number of nouns and long words. Nouns are all nouns that are not either proper names or descriptive names. As nouns are important parts of a scientific language and are carriers of information, nouns are significant parts of most measures of the information load. In this study, long words are defined as words consisting of more than six characters; as such, long words in Swedish are directly related to a text’s difficulty (Björnsson, 1968).

Long words might be extended nouns or nouns created by nominalizations, but can also be the result of the ability of the Swedish language to create compound words. Long words therefore pack a lot of information into one word and are thus considered an important part of this meaning dimension. The need for a measure of information load when analysing texts used in school as implied by Wellington and Osborne (2001) is therefore addressed.

In the meaning dimension *Precision*, words that specify the characteristics of entities or actions are brought together, i.e. determinants to complex noun phrases common in scientific language. This group, in this study named “precifiers” for short, consists of modifiers (adjectives, adverbs and participles), amounts (counting words) and single letters or numbers naming entities (descriptive names). The “precifiers” thus reflect the level of *Precision* of the language.

The meaning dimension *Personification* captures personal relations within the text or between the text and the reader by using the number of proper names and personal pronouns in the item. Proper names are defined as names of people or places intended to give a “real-life context.” Personal pronouns consist of all first, second and third-person pronouns that refer to a person or groups of people.

The meaning dimension *Presentation* focuses on the presentation of the item’s information to the reader. It is built up through the number of subordinate clauses and passives in an item, using the two ways to form passives in the Swedish language.

Calculating meaning dimensions

Each meaning dimension consists of different linguistic features, all calculated per word in the item (Table 2). To be able to add the linguistic features of different concentrations together, each linguistic feature was normalized by having its standard score (z-score) calculated (see e.g. Field, 2013). For example: as there are always several nouns present in an item, but not necessarily many long words, without normalization any effect long words might have would be drowned by the sheer number of nouns. The normalized variables were then added together into meaning dimensions, and were thereafter divided by the number of variables added together.

All meaning dimensions except *Packing* have a lowest value equalling none of the measured linguistic features present. As nouns are one of the variables used for measuring the level of *Packing*, and nouns are always present in items, a zero-level does not exist for *Packing*.

RESULTS

The levels of *Packing*, *Precision*, *Personification* and *Presentation* were calculated for each item as described above. Results are presented in relation to the four subjects within TIMSS and compiled in one bar chart and five box-plots below. They are referenced in more detail under each subject’s paragraph and summarised in Table 3. The y-axes of all figures except Figure 2 (number of words in items) show the standardized values of the meaning dimension measured. As standardized values have a mean value of zero, a negative value in a figure signals a value lower than the average of all science items, and a positive shows a higher value than the average.

Figure 1 gives an overview of the meaning dimensions for each subject, i.e. subject-specific profiles of the meaning dimensions. Differences as well as some similarities in the average language use among the four subjects in TIMSS 2011 are visible in Figure 1. The box-plots in Figures 2 to 6 show the results in more detail, where outliers and extreme values are excluded when calculating the boxes and whiskers (Field, 2013). Such unusual values are marked with ^o or * in the box-plots.

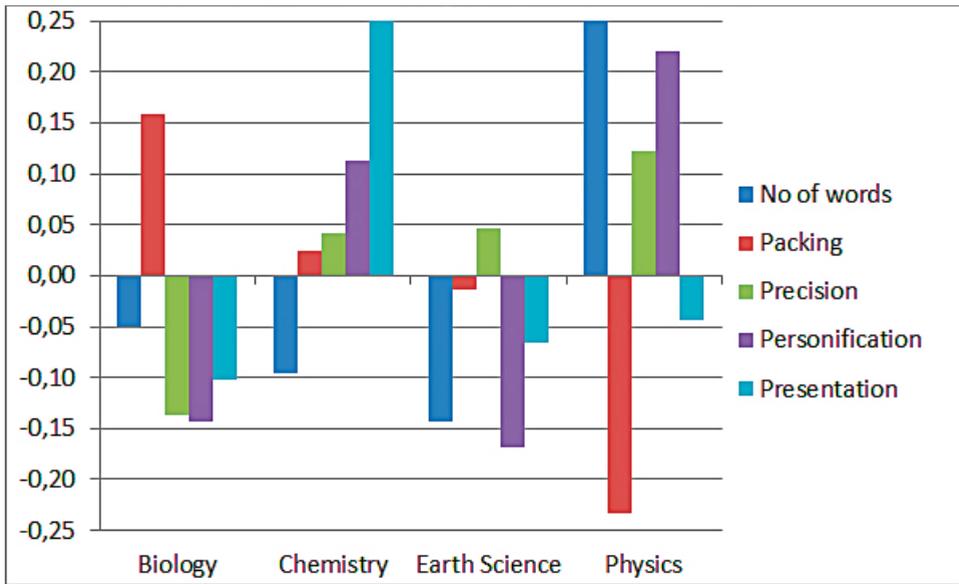


Figure 1. Mean values of meaning dimensions for TIMSS 2011 science items.

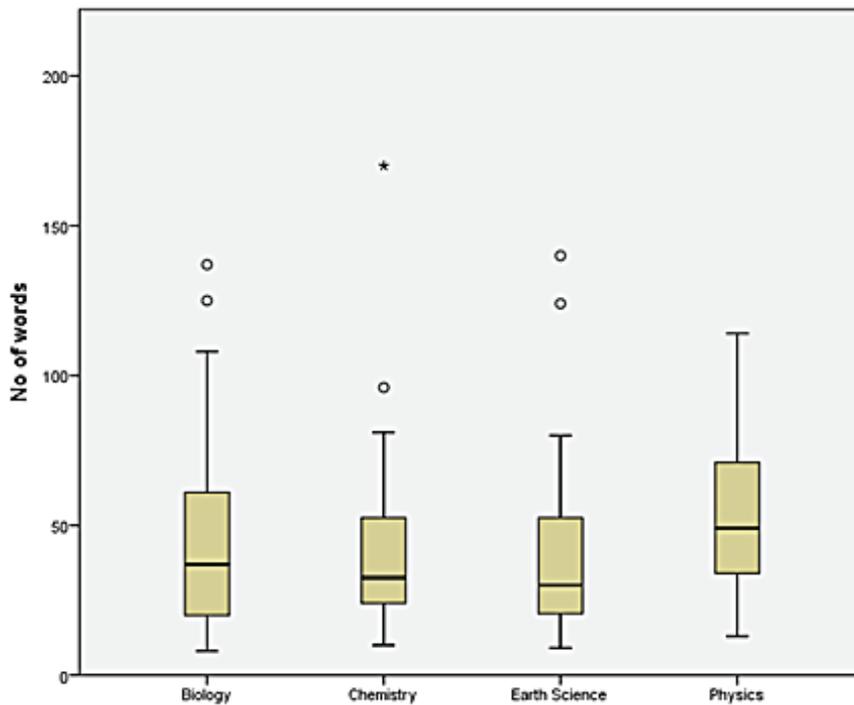


Figure 2. Number of words in TIMSS 2011 science items.

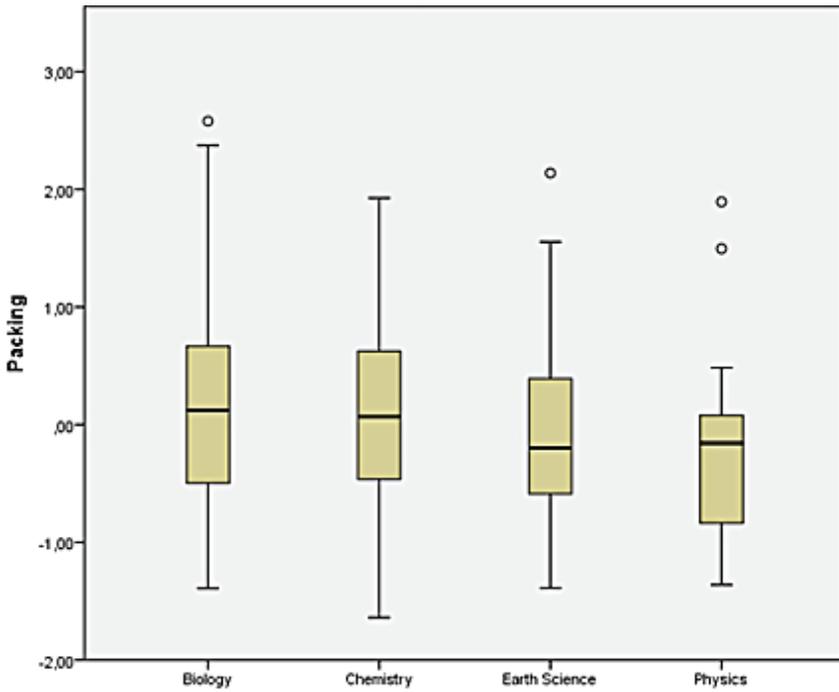


Figure 3. The meaning dimension Packing for TIMSS 2011 science items.

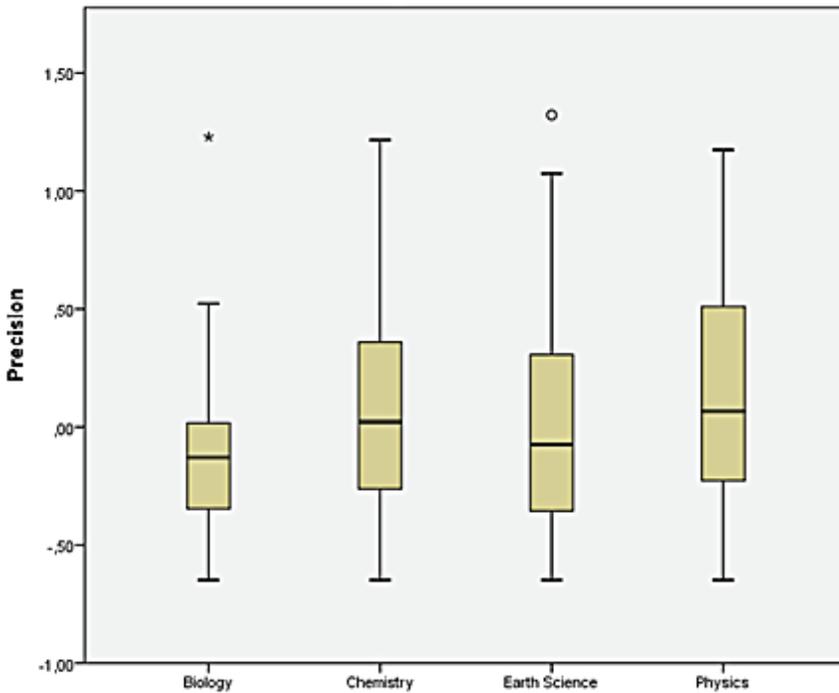


Figure 4. The meaning dimension Precision for TIMSS 2011 science items.

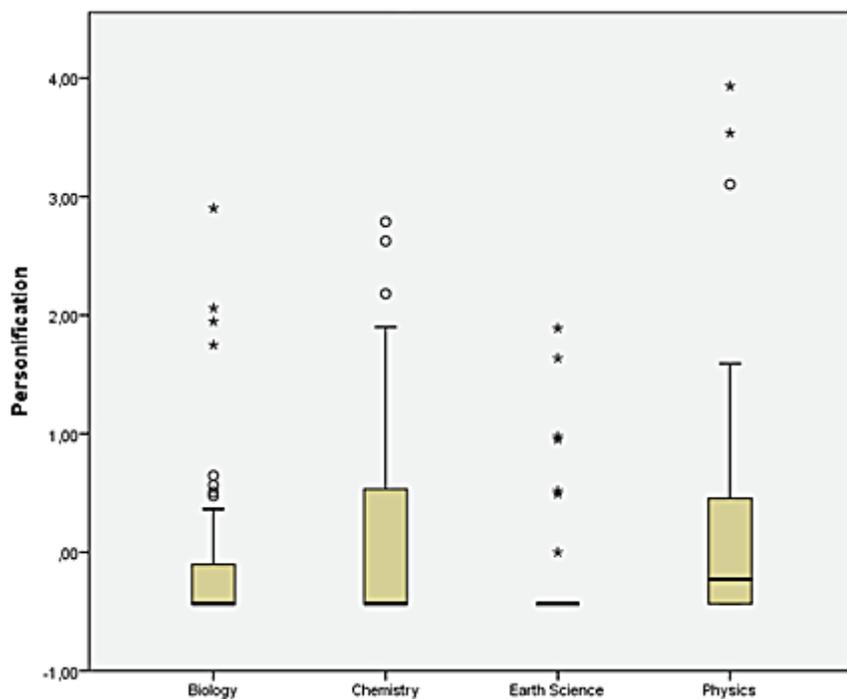


Figure 5. The meaning dimension Personification for TIMSS 2011 science items.

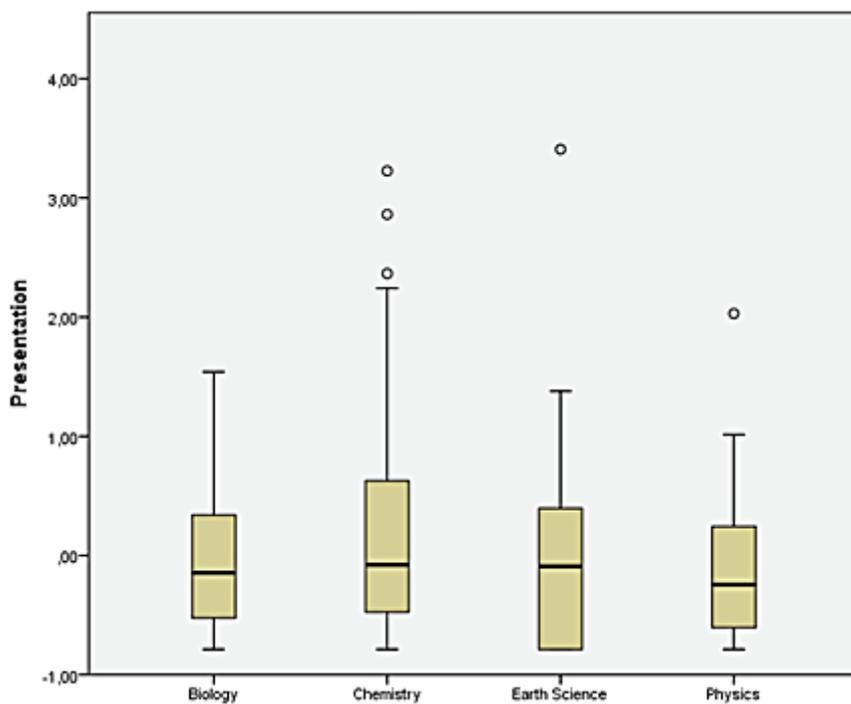


Figure 6. The meaning dimension Presentation for TIMSS 2011 science items.

Biology

Results show that the average language in the biology items in TIMSS expresses what the texts are about with a high level of *Packing* and quite a low level of *Precision*. *Personification* and *Presentation* are also expressed at low levels (Figure 1). However, the dimension of *Packing* varies a lot between items (Figure 3); the same goes for the number of words in the item (Figure 2). Such large variations are not found for the dimensions *Precision*, *Personification* and *Presentation* (Figures 4, 5, and 6).

Interestingly, the average language use in biology differs from the language use in physics. With the exception of *Presentation*, all other meaning dimensions show opposite signs (Figure 1). When biology has a high value, physics has a low value and vice versa.

The following example (Example 2) shows typical features of a biology item. It is a very short item with a very high level of *Packing*. In just thirteen words in the Swedish version, there are six nouns, five of which are also long words.

The uterus (womb) is part of the reproductive system in mammals.
Name one function of the uterus.

Example 2. Biology, item S032007 (Foy et al., 2013).

FRÅGA S032007

Egenkonstruerade svar

Livmodern är en del i däggdjurens fortplantningssystem.
Näm en funktion som livmodern har.

Swedish version. Biology, item S032007 (Skolverket, 2014).

Furthermore, Example 2 illustrates the typical low levels of *Precision*, *Personification* and *Presentation* in the language used in biology. In this item, no “precifiers” are present at all. It also mirrors the fact that the use of people or places is very uncommon in biology items. *Presentation* is also low in this example, as there are no passives and only one subordinate clause.

It can thus be concluded that the most salient attribute of the scientific language used in biology in TIMSS is the absence of *Personification*, i.e. it is an objective impersonal language. Much lower levels of *Precision* are also found in the language used in biology compared with the other subjects. A somewhat less typical feature is the large variation concerning *Packing*.

Chemistry

Regarding *Presentation* and *Precision*, language use in TIMSS for chemistry items is quite diverse. With measurements in both *Packing* and *Precision* evenly dispersed (Figures 3 and 4), the presence (or absence) of long words, nouns or “precifiers” does not seem to be a significant characteristic of the language used in chemistry.

The language used in chemistry items shows a higher level of *Personification* than both biology and earth science. Although the median is null (Figure 5), indicating that the use of proper names and personal pronouns is uncommon, the results show similarities to the language used in physics, which is high in *Personification* (Figures 1 and 5).

Chemistry is the only subject with a high mean value for the meaning dimension *Presentation* (Figure 1), but when disregarding the outliers, the medians of all four subjects are nearly the same (Figure 6). It can thus be concluded that although subordinated clauses or passives are not present in the language used in all chemistry items, they are more commonly used than in the other subject languages.

The short item below (Example 3) shows many of the characteristics of a chemistry item. It is quite low in *Packing*, having only three nouns and four long words in seventeen words, and with only one adjective, *kemisk* (chemical), it is also quite low in *Precision*.

Write down one thing you might observe that shows that energy has been released during a chemical reaction.

Example 3. Chemistry, item SO32679 (Foy et al., 2013).

FRÅGA S032679

Egenkonstruerade svar

Beskriv en sak som du kan observera som visar att energi har frigjorts vid en kemisk reaktion.

Swedish version. Chemistry, item SO32679 (Skolverket, 2014).

Given the rare occurrences of personal pronouns and proper names in science items in general, the single use of the personal pronoun *du* (you) actually makes the language used in Example 3 high in *Personification*. The very high values of *Presentation* in some chemistry items are illustrated here, as Example 3 has one passive form *frigjorts* (been released) and three subordinate clauses in just seventeen words.

The language use in the TIMSS chemistry items is thus somewhat high in *Personification*, i.e. more inclined to place items in a context with people or places. *Presentation* is high, indicating an occasional use of a more complex language with passives and subordinations.

Earth science

Language use in earth science items is fairly close to an average science item for both *Packing* and *Precision* (Figure 1). It is quite similar to the language use in chemistry (Figures 1, 3 and 4) but with a slightly lower use of “precifiers” (Figure 4).

The language in earth science has the lowest mean value of *Personification* (Figure 1). In fact, the mere seven items containing any personal pronouns and/or proper names are all classified as extreme values (Figure 5).

Regarding *Presentation*, the average for language use in earth science items is fairly close to that of an average science item (Figure 1). However, almost 29% of earth science items do not contain any subordinate clauses or passive forms at all. This can be seen in Figure 6, as earth science has the lower quartile on the equivalent of null.

With just 34 items to choose from, it is challenging to find a typical example of an earth science item in terms of all four meaning dimensions. With fifteen words and just four nouns and two long words, Example 4 is a lower-than-average earth science item in *Packing*, but with three “precifiers”,

the adverbs *hur* (how) and *långt därifrån* (far away), Example 4 is higher than average in *Precision*. The item has no personal pronouns or names, nor are there any passive forms; there is only one subordinating clause. The level of *Personification* in Example 4, as it is for most earth science items, is therefore null, with an average level of *Presentation*.

How does water that has evaporated from the sea end up as rain on land many miles away?

Example 4. Earth science, item S042317 (Foy et al., 2013).

FRÅGA S042317

Egenkonstruerade svar

Hur kan vatten som avdunstat från havet falla ner som regn på land, långt därifrån?

Swedish version. Earth science, item S042317 (Skolverket, 2014).

Thus the most prominent language use attributes for earth science in TIMSS are not the presence of certain linguistic features, but rather the absence of them. There is an absence of linguistic features that establish personal relations and many items also lack passives and subordinating clauses.

Physics

TIMSS physics items have far more words per item on average than the other subjects (Table 1, Figures 1 and 2), and excluding the outliers of the other subjects, the wordiness in physics becomes even more apparent (Figure 2).

The language used in physics shows very low values for *Packing* (Figures 1 and 3) and disregarding two outliers, one can see that almost 75% of the physics items are below average value for all items (Figure 3). The use of nouns and long words is thus not as common as in the other subjects. Though they are apparently not necessary in all physics items, “precifiers” are still quite common, especially compared with the biology items. Physics language in TIMSS often uses words that establish personal relations or place the task in a context with “real” people or places. As a result of this use of agents, physics language has the highest personification mean (Figure 1) and is the only subject where the use of proper names and personal pronouns is so frequent that the median is above null (Figure 5). Regarding *Presentation*, the language use is quite similar to the biology items.

Example 5 below exemplifies both the wordiness of language use in physics items in TIMSS and the low levels of *Packing*: there are only twenty-four nouns and fifteen long words out of ninety words total. However, with only eleven “precifiers”, Example 5 is very low regarding *Precision* – almost as low as the median value for biology items. With four personal pronouns, Example 5 is slightly above the physics mean. With one passive form and two subordinating clauses, the level of *Presentation* is similar to the language use in an average physics item.

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A man climbed to the top of a very high mountain. While on the mountain top, he drank all the water in his plastic water bottle and then put the cover back on. When he returned to camp in the valley, he discovered that the empty bottle had collapsed.

Which of the following best explains why this happened?

- (A) The temperature is lower in the valley than on the mountain top.
- (B) The temperature is higher in the valley than on the mountain top.
- (C) Air pressure in the valley is lower than on the mountain top.
- (D) Air pressure in the valley is higher than on the mountain top.

Example 5. Physics, item S032279 (Foy et al., 2013).

FRÅGA S032279 **Flervalsfråga**

En man klättrade upp på toppen av ett mycket högt berg. Uppe på toppen drack han upp allt vatten i sin plastflaska och satte sedan tillbaka korken. När han kom tillbaka till baslägret i dalen upptäckte han att den tomma flaskan hade tryckts ihop.

Vilket av följande alternativ ger den bästa förklaringen till detta?

- (A) Temperaturen är lägre i dalen än uppe på toppen.
- (B) Temperaturen är högre i dalen än uppe på toppen.
- (C) Luftrycket i dalen är lägre än uppe på toppen.
- (D) Luftrycket i dalen är högre än uppe på toppen.

Swedish version. Physics, item S032279 (Skolverket, 2014).

Prominent characteristics of the language in physics items in TIMSS are many words, and situated tasks, i.e. high levels of *Personification*. *Precision* is often high in physics language, while *Packing* is low.

Summary of results

The graphic description of meaning dimensions (Figure 1) shows that each subject has its own profile. The results also show that for some meaning dimensions, different subjects have a similar language use, while other subjects differ from one another.

Table 3 summarizes the results concerning the differences and similarities of language use in biology, chemistry, earth science and physics shown in Figure 1 and 3-6, showing each subject's deviations (Dev.) from the average language use in all science items and the dispersions (Disp.) of measurements.

Table 3. Overview of subjects' deviations from average language use in all Swedish science items in TIMSS 2011 and the measurements' dispersions.

| Language use in: | Meaning dimensions | | | | | | | |
|------------------|--------------------|--------|-----------|--------|-----------------|---------|--------------|-------|
| | Packing | | Precision | | Personification | | Presentation | |
| | Dev. | Disp. | Dev. | Disp. | Dev. | Disp. | Dev. | Disp. |
| Biology | + | H, (S) | - | L, (S) | - | A, S | 0 | A, S |
| Chemistry | 0 | H | 0 | H | + | H, S | + | H, S |
| Earth Science | 0 | A | 0 | H | - | (NA), S | 0 | A, S |
| Physics | - | L, (S) | + | H | + | H, S | 0 | A, S |

Deviations: +: Above average; -: Below average; 0: Close to average
 Dispersions: H: High; L: Low; A: Average; (NA): Too few valid measurements
 S: Skewed distribution (i.e. many low scores); (S): Slightly skewed distribution

Packing, the proportion of nouns and long words, is usually higher in biology language use than in physics, with chemistry and earth science falling in between. Regarding *Precision*, almost 9% of the items do not use any adjectives, adverbs, participles, counting words or descriptive names at all. Still, it is clear that compared with language use in the other three subjects, biology has much lower values in *Precision*, and physics has slightly higher values than chemistry and earth science.

Most science items in TIMSS are written without proper names or personal pronouns, thus producing an abundance of low scores for all subjects in *Personification*. The phrase “Motivera ditt svar” (Explain your answer) in the constructed-response items is responsible for 20% of the 124 personal pronouns occurring in TIMSS items. That phrase occurs in 52% of the constructed-response questions in physics, and in only 29% in biology. The occurrence is even lower in chemistry (15%) and earth science (12%). The language in physics items, and to some extent in chemistry items, does however make more use of names and places than biology, while earth science items tend to use language that avoids names and personal pronouns. Only 46% of physics items do not refer directly to the reader or mention people and/or places, while 70% of the other three subjects' items together do not mention people or places.

The use of subordinating clauses and passives to present information is more frequent in the language in chemistry. However, 23% of TIMSS items do not use these linguistic features at all, thus resulting in skewed distributions for all subjects. It is noteworthy that, contrary to the item writing guidelines (Mullis & Martin, 2011), 47% of the Swedish items use passive forms.

Finally, compared with the other subjects, the average physics language in TIMSS uses more words.

DISCUSSION

The results of this study challenge the notion of a uniform scientific language that – regardless of subject – packs a scientific text with precise information presented in complex ways with downgraded personal relationships, as it has been shown that language use varies in the different scientific subjects. However, since this study only assesses language use in one context – a test situation with questions from TIMSS – further research is needed to determine whether this variation also applies to other contexts and texts.

As *Packing* and *Precision* have been operationalized in this study, with nouns and long words on the one hand and “precifiers” on the other, differences in language use between the subjects can be seen. Packed, dense language with low precision is a prominent feature of biology as a whole, although single items show a large variety in *Packing* and a lower variety in *Precision*. Physics shows the opposite, with low *Packing* and a higher use of “precifiers”, smaller variations between items in *Packing*, and higher in *Precision*. Chemistry and earth science are closer to average, although with large dispersions for single items. The results from the analysis of *Packing* in Figure 3 demonstrate what might be a lowest threshold value for all subjects except chemistry. Thus, the scientific language of chemistry might be able to use fewer nouns and long words compared with what the other subject languages require to convey their content. However, this is speculative, as only two chemistry items are below that threshold. The opposite behaviours of physics and biology regarding the meaning dimension *Packing* are consistent with Wellington and Osborne’s (2001) claim that physics often has shorter “concept words” while biology has longer “naming words”. However, a more detailed analysis of the vocabulary must be carried out to investigate whether this is the cause of the observed differences. A deeper analysis could also show whether long words are predominantly abstractions (i.e. nominalizations or compound nouns), other types of nouns or if they even belong to other word classes. The high level of *Precision* in physics is not caused by the fact that physics items require mathematical calculations, thus increasing the counting words variable. In fact, only one item out of 197 requires any actual calculations, and that item is found in chemistry. Perhaps expanded noun phrases, where “precifiers” like adverbs and adjectives are important components, are not as common in TIMSS biology items as they are in physics items. Whether this observed difference is due to a greater need in physics for technical terms that require characteristics of actions/entities specified, or if something else causes this difference, is a subject for future research.

Regarding interpersonal meaning, the common view that scientific language avoids personal relations and personalized contexts is reflected by the meaning dimension *Personification*, as it is operationalized in this study by personal pronouns and proper names. Compared with the language use in biology items in TIMSS, a salient trait of the language used in physics items, and in some chemistry items, is the use of words signalling that people and/or places are participants in the context of the item, or that establish a personal relationship to the reader, i.e. by using “you” or “your”. The design of constructed-response items in different subjects explains some of these differences. In physics, the student is often asked to mark one correct answer among several options, followed by the phrase “Explain your answer”, whereas biology often has two questions in one sentence: “Which X is the cause and in what way is X...” without the use of a pronoun. Furthermore, the few occurrences of proper names in earth science items are in everyday situations, while in chemistry, proper names are primarily used in connection with people conducting experiments. For physics and biology, there is a slight preference for the use of personal pronouns and names in experimental situations. This placement of fictitious people in a laboratory context – especially in chemistry items – instead of in an everyday context might have implications for how students respond to the questions (cf. Serder & Jakobsson, 2015). As earth science is not a subject in Swedish curricula, it is noteworthy that six out of the mere seven earth science items using names or personal pronouns would likely be classified as physics items in the Swedish school system.

Language use in biology and physics seems to be at opposite ends regarding all meaning dimensions except for *Presentation*, which reflects the textual meta-function as it is operationalized in this study by passive constructions and subordinated clauses. Instead, they tend to have similar and less complex language use, while language use in chemistry items seems more complex. As use of subordination and passives are both considered harder to process for a reader, perhaps many teachers are unaware of the additional difficulty chemistry students might therefore have. It is noteworthy that many items, especially in earth science, are written without any use of subordinations and passives at all, thus presenting the information in a less complex form. However, given that the guidelines (Mullis & Martin, 2011) state that the active verb form is to be used, it is interesting to note that almost half of the Swedish science items use passives.

Regarding text length, biology, chemistry and earth science language in TIMSS all have a similar average length, although biology shows greater variety between items. As physics has both the highest minimum and the lowest maximum number of words and a very high average of words per item compared with the other subjects, this is not caused by a few items containing many words. Rather, it is caused by general wordiness in physics items. That does not automatically imply that wordiness is a typical attribute of Swedish physics language. As the Swedish version of TIMSS is translated from the English version, it is possible that the origin of the wordiness can be found in the original English text, or could even be inherited from some characteristics of the English physics language. Although tests translated from English to another language often become longer (Oakland & Lane, 2004), that does not mean this must be the case for the Swedish language, especially with the Swedish ability to create compact compound words, as previously mentioned (Examples 1-5 all have fewer words in the Swedish version). Above all, translation-induced wordiness should not influence physics alone. To find the origin of the abundance of words in physics, an analysis comparing the Swedish version with the original English version must be carried out.

It is up for discussion whether “school science” is “real science” or not, and the same goes for a “proper scientific language” when used in a school context. Can an eighth grade science lesson, textbook, or as in this case, a test, really be said to use proper scientific language, given that the language used probably differs from what you would typically find in, say, a physics thesis? Veel (1997) states that to make science learnable at all, pedagogical changes must always be made and “school science reduces, simplifies, generalizes and idealizes centuries of scientific activity, in order for students to assimilate important understandings and move on to ‘real science’, i.e. empirical research and dispute” (p. 169). Adopting the notion of scientific language as a fundamental part of science itself (cf. Banks, 2005; Halliday & Martin, 1993; Halliday & Webster, 2004), the reductions and simplifications that Veel deems necessary in a school science context must therefore also concern language use in science. However, texts used in school science cannot be written completely without the linguistic features of science, as the science itself would then be reduced or even vanish.

Shanahan and Shanahan (2008) argue that “there are differences in how the disciplines create, disseminate, and evaluate knowledge, and these differences are instantiated in their use of language” (p. 48), and therefore see a need for reading and writing instructions that are increasingly disciplinary as students move through the school system. If the language of science has coevolved with science over hundreds of years (cf. Halliday & Martin, 1993, p. 12), it is likely that as the different scientific subjects have emerged and evolved during the course of time, so has their use of language. Therefore, researchers, authors and especially teachers must be aware not only of linguistic features and their functions in science, but also of differences in how such features are used in the different subjects. Science teachers who are informed about the specific linguistic demands of their subject can help students understand more than just *what* a text says. Students that also understand *how* and *why* language is used in a particular way in a subject are more likely to understand similar texts and to start using subject-specific language in appropriate ways.

CONCLUSION

While many linguistic studies address the differences between a (single) “scientific language” and other subject languages, or describe certain aspects of the scientific language in one particular subject, this study has instead compared differences in scientific language use *between* the different scientific subjects. By analysing similar texts from different scientific subjects, this study has shown that there are indeed differences in language use between scientific subjects – at least in the case of TIMSS 2011. As international teams develop TIMSS items, which are then subjected to several expert reviews and a field test before the items are selected (Mullis, Drucker, Preuschoff, Aurora & Stanco, n.d.), any substantial differences in language use in items between subjects are unlikely to be attributed to differences between the groups creating the items. Rather, these differences reflect the features and functions of the scientific languages.

As this study's findings only address language use in science items from the Swedish version of TIMSS 2011, further studies must be carried out to see if the results comply with corresponding analyses of other tests and texts used in a school science context. Interesting comparisons of language use could be made using items from the PISA assessment, the Swedish national standard tests or from science textbooks. Future studies might also include comparisons with how language is used in other school subjects or in texts using a more colloquial language.

The theoretical framework not only allows for analysis of longer text passages; it is also plausible that meaning dimensions could be used for analysing texts in other languages, since the formulas do not use any language-specific coefficients. Adaptations might be needed, i.e. finding relevant linguistic features that express the meta-functions in different types of texts or languages. Such linguistic features could be of other types than those studied here, e.g. vocabulary, appraisal, lexical chains or theme-rheme structure. For an example of the meaning dimensions applied to mathematical items, see Bergvall, Wiksten Folkeryd & Liberg (2016).

By studying the ways in which item meaning dimensions correlate with performances by the different groups of students answering the items (cf. Persson, 2016), the meaning dimensions could be used as a tool not only to aid the design of science items, but also to highlight difficult features of a scientific language, both generally and in specific subjects.

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