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EXPLORING THE SCIENTIFIC SEMANTIC NETWORK OF "FORCE" BY COMPARING PHYSICS TEXTBOOKS FROM KOREA, THE UNITED STATES, AND SINGAPORE

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Abstract

This study aims to extract a scientific semantic network for the concept of "force" by identifying common linguistic phenomena across different countries and languages. High school physics textbooks from Korea, the United States, and Singapore were analyzed. The words used in the textbooks were compared, and common words were extracted. Text network analysis was applied to examine the connections among these words, leading to the derivation of a scientific semantic network representing the concept of force. The results revealed significant commonalities among the textbooks, despite differences in language and culture. The 89 common words accounted for about 41% of the total text, and the top 10 physics terms made up approximately 20%. The scientific semantic network can be used to develop linguistic strategies for teaching physics concepts, propose new methods for evaluating students' understanding of concepts, and create language models for teachers.

Keywords – Physics education, Science language, Science textbook, Scientific semantic network, Text network analysis.

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1. Introduction

No one would doubt that language is of great importance in human life. And as language is of high importance, people have long been trying to identify the substance and function of language, especially its relation to the human mind. However, despite the efforts of Galilei, Descartes, Newton, and other prominent scholars, a fully agreed conclusion has yet to be reached, and the relationship between language and the human mind remains a significant subject of inquiry. But one thing is clear: language is beyond the communication system and reflects human thought, the mental world, like a mirror (Chomsky, 2002; Hauser, 1996). Many scholars have been trying to look closely at individual thoughts (Aitchison, 1997) or the characteristics of a linguistic group (Miller, 2006).

Language is composed of numerous words (Miller, 1996), and people form and communicate meaning through forming connections between words (Kelly, Barr, Church & Lynch, 1999). Analyzing the relation between words in a language can provide information about the speaker's thoughts. The relations between words here are more like a conceptual relation than a grammatical one. Grammar is a rule that organizes a word, clause, sentence, etc., so the relationship between words is linearly identified. On the other hand, if the concept of a word is assumed to consist of different component words, the conceptual relation will include the relation between these word elements, and the relation between one concept and another. Therefore, conceptual relations are much wider, more complex, and multidimensional than grammatical ones. From a cognitive linguistics standpoint, grammatical relations can be included in conceptual relations. Research by Vygotsky (1976) also equated the development of child thinking with the development of a conceptual relations between words. The conceptual relations between words that make up a language can be a structure of specific knowledge or a framework of thought. The fact that language implies a structure of knowledge and a framework of thought (Darian, 2003) can also be interpreted in the same context. Based on this cognitive linguistic perspective, this study deals with the conceptual relations between words as units that make up a language.

In a similar vein, a language spoken in the field of science contains a system of scientific knowledge that is academically accepted; therefore, understanding the language of science means mastering scientific thinking (Darian, 2003). For this reason, when students are taught science, it is important to ensure that students correctly learn the language of science. The science language here refers to an ideal form of language containing the knowledge system of science and does not refer to the discourse used in science society or science educational situations. The scientific concepts we deal with in school science education may be a very basic part of the entire scientific knowledge or the knowledge system that scientists have. For this fundamental fraction, a group of scientists may possess the most ideal knowledge system. Therefore, science teachers or science textbooks should organize a discourse that students can understand easily, but should melt the ideal knowledge system of scientists in the discourse so that it can be passed on to students well. And finally, students can form their own discourse, and the more similar the conceptual relations that melts in the discourse to those of scientists, the more successful learning can be considered. In fact, the more similar the conceptual relations between words that students have in their mind to the conceptual relations extracted from the text of the science textbook, the higher their understanding of the concept has been proven (Yun, 2020a).

There has been much discussion by researchers on the fundamental definitions and importance of the language of science (Fang, 2006; Ford & Peat, 1988; Jaipal, 2009; Maskill & Cachapuz, 1989). However, detailed research on the substance of scientific language and how it is implemented is currently lacking. Although there are some studies dealing with grammatical strategies to educate science languages (Halliday, 1993; Schlepegrell, 2004), these studies focus on uncovering the grammatical relations between words in which science languages are expressed, rather than revealing the conceptual relations latent in science languages. Strategies for teaching grammar, style, and vocabulary of science language can be made more effectively only after an empirical study that sheds light on the fundamental conceptual connections of science language. This lack of empirical and phenomenal research on scientific language hinders theoretical discussions that could lead to changes in the field of school education. It can be argued that the lack of research and development of teaching strategies for scientific language (Rupley & Slough, 2010) is caused by a lack of empirical research on scientific language. For this reason, in this study, we took an empirical approach to scientific language.

As single words have organic connections with several other different words or concepts (Sternberg & Ben-Zeev, 2001), so too does the concept of force have linguistic connections with other words. The words that make up a concept can include both scientific terms and everyday words. Research by Yun and Park (2018) defined the connections of words that constitute a scientific concept shared among experts as a "scientific semantic network." When physics is taught to students in school, the academic content is the same across different countries and languages. For example, when teaching the concept of force, the concept remains the same in different countries. Therefore to teach scientific language to students, it is necessary to identify the scientific semantic network that constitutes specific scientific knowledge or scientific concepts.

Currently, there is no clear standard for the scientific semantic network. Therefore, the language used in science classes is also being used somewhat ambiguously because there are no clear guidelines. Depending on the method of teaching, such as with textbooks or teachers, the language composition used to explain the concept of force can vary widely. According to previous studies, even textbooks that teach the same curriculum differ considerably in terms of the words they use, and teachers also use different expressions and words when teaching (Yun & Park, 2018). If diverse languages are able to teach the same scientific knowledge, there must be a common element to these languages. This common element is likely to involve key scientific knowledge, namely the scientific semantic network. Thus, since science knowledge encompasses the country, language, and society, the present study assumes that the languages that teach a particular concept, even in different countries and societies and with different languages, contain common scientific knowledge (i.e., the scientific semantic network).

Finding a scientific semantic network that encompasses language and culture can help science educators to develop strategies for teaching and learning science in many ways. First, it contributes to finding the key elements that make up the scientific concept and their connection structure. It is very important to have a concrete and accurate grasp of the concepts to teach. But the elements that make up the concept and their connection structure are difficult to be found completely either through the intuition of the experts or through deductive methods alone. This is because most people do not recognize what words they specifically combine when using a language, and they often have difficulty presenting the concept elements or definitions of the word, even if they are fully aware of the meaning (Miller, 1996). The fact that concepts are often inaccurate or insufficient even in science teachers' discourse or science textbooks (Anakkar, 2014; Yun & Park, 2018) shows the need for a standardized scientific semantic network. So when we specifically extract the key elements and their relations, that make up the concepts to be taught, that is, extracting the scientific semantic network, it will be easier for teachers to accurately implement them in class. And in this case, students would be exposed to a more ideal scientific semantic network, which puts them in a more favorable environment for acquiring accurate concepts. Second, it can help establish strategies for teaching and learning science in intercultural situations. Intercultural teaching and learning in science education is becoming an increasingly important issue (Bilek, 2018). Language in classroom consists of managing activity and presenting academic content (Schleppegrell, 2004). Scientific semantic network shows the relations between the core and essential words that make up the academic content. And the results that will be presented in the end of this study will show that they are common regardless of language or culture. Third, it can be used as a framework for teachers' discourse composition to improve the quality of classes. When teachers explain concepts, it is insufficient to list the definitions of concepts, and they need to use sufficient language for concepts (Jeppsson, Haglund & Strömdahl, 2011). At this time, the scientific semantic network will help science teachers build a substantial discourse in terms of scientific knowledge by providing a framework for forming a discourse. Therefore, we attempt to extract a scientific semantic network for the concept of force by collecting texts that describe this concept from science textbooks written in different countries and extracting word-linked relations that are common among these texts. Force is not only a fundamental concept in Newtonian mechanics, but also a prerequisite for understanding physics as a whole (Carson & Rowlands, 2005; Tomara, Tselfes & Gouscos, 2017). The fact that many science education researchers have focused considerable attention on how students acquire the concept of force underscores its central importance in physics learning (Coelho, 2010; Savinainen & Viiri, 2008; Stoen, McDaniel, Frey, Hynes & Cahill, 2020) Accordingly, this study selected force as the focal concept for analysis, given its critical role in students' understanding of physics.

Even though language and culture are different, if there is a common structure in the language used to describe a particular scientific concept, it would very likely be a scientific semantic network. In previous study scientific semantic network had been extracted from dozens of science textbooks published within a country (Yun & Park, 2018). However, it has not yet been confirmed how much it is shared internationally, and whether a common scientific semantic network that really transcends language and culture can be empirically extracted. Thus, the purpose of this study is to extract the scientific semantic network shared by textbooks used in countries with different languages and cultures. Science teachers or science textbooks need to include a scientific semantic network when describing a particular concept, and the rest of the language to describe it can be optionally constructed. This study aims to explore the scientific semantic network for force by extracting a common linguistic structure from the text of the science textbook force section of three countries: South Korea, the United States and Singapore. The three countries were selected in order to compare the researcher's native language, Korean, with English as an international language, and to examine cultural differences by comparing the United States and Singapore, which both use English but represent distinct cultural contexts. The results of the study would provide information on how reasonable the inter-country science textbooks comparison method is in extracting the scientific semantic network.

1.1. Research Question

- What words are commonly used to describe 'force' in high school-level physics textbooks in three countries, Korea, the United States and Singapore, and what percentage and importance are they in full text?
- How are the words commonly used to describe 'force' in textbooks in the three countries linked?
- Is it reasonable to use a method of analyzing science textbooks from different countries to extract the scientific semantic network that encompasses countries and languages?

2. Research Methodology

2.1. General Background of Research

The semantic network is a knowledge representation structure that expresses semantic relationships between concepts in the form of nodes and links. It is based on the spreading activation model, in which concepts are differentially activated depending on the strength of their connections, and those with stronger links are more readily retrieved (Collins & Loftus, 1975). Although the theoretical foundations of semantic networks were established in the 1960s, they continue to serve as a valuable framework in fields such as psychology, education, and computer science (Christensen & Kenett, 2023; Pereira, Grilo, Fadigas, Souza-Junior, Cunha, Barreto et al., 2022; Sun & Wei, 2009). While modern advanced artificial intelligence models do not explicitly generate or directly use traditional semantic network structures, they are nonetheless grounded in its theoretical principles, especially in knowledge representation, language understanding, and inference-based AI technologies (Heylighen, 2001).

The present research is a quantitative study employing an empirical linguistics approach grounded in cognitive linguistics theory and semantic network models. A distinctive feature of this study is the conceptual distinction—within the framework of constructivist and cognitive linguistic perspectives—between students' internalized knowledge, represented as a mental semantic network, and expert-level disciplinary knowledge in science, represented as a scientific semantic network

A text network analysis was used as an analysis method, but was performed by referring to the methods of prior studies (Yun & Park, 2018) to reveal the characteristics of scientific language. The period spent on the study was about one year, and most of the study period was spent on refining and processing text data.

2.2. Textbooks

High school physics textbooks from three countries (Korea, the United States, and Singapore) were selected for the study. Korea is a Korean-speaking country, and English is spoken in the United States and Singapore. A physics textbook from each of the three countries was selected. In the case of the U.S., we selected the high school textbook Regular Physics as the most widely used textbook (Tesfaye & White, 2014). For Korea, around 10 textbooks had been published, but there was no open data on the distribution of usage by textbook, so one textbook published was selected at random for the research. While nearly ten different publishers produce science textbooks in Korea, only a small number of publishers are responsible for textbook publication in Singapore. A textbook recommended by a field teacher was selected. The three textbooks used in the study all correspond to physics textbooks at the regular or ordinary level of high school. Although the curriculum policies and textbook regulations may differ slightly across the three countries, and the grade level at which the "force" unit is taught in high school may vary, all three textbooks analyzed in this study are designed for the high school level, cover the topic of "force," and serve as instructional texts aligned with their respective national curricula. In addition they are at a lower level than the AP course.

Texts of force unit that explain the concept of force were extracted from the three selected textbooks. The selected texts did not include explanations of force and work, or force and tools; rather, only explanations of the theoretical concept of force were extracted. Information on the textbooks studied and the amount of text reviewed in the study is given in Table 1. In Table 1, "type" is the kind of word used in the text, and "token" means the total amount of words used, including the duplicate use of words. Therefore, type is an indicator of how many different words were contained in the text, and token is an indicator of the amount of text.

Country	Textbook	Type	Token
Korea	Physics Ⅰ	495	2,078
USA	Holt Physics	628	3,287
Singapore	Physics O	513	1,847

Table 1. Number of words used in three textbooks

According to Table 1, the amount of text in the Korean and Singaporean textbooks was similar, and the United States textbook was considerably longer. The physics textbooks from the three countries used between 500 and 600 kinds of words within a total of 2,000 to 3,000 words dealing with the concept "force".

2.3. Comparison of Words Used in Three Textbooks

To compare and contrast the usage patterns of words used to explain the same scientific concepts in science textbooks from the three countries, the frequency and co-occurrence of the words extracted from each textbook were analyzed. To standardize the language, all words used in the Korean textbooks were translated into English, and all inflected words were converted to their base forms. For instance, plural nouns were changed to singular forms, and verbs in past or inflected forms were converted to their base form. The frequency of words used in each text was analyzed using AntConc 3.2.4 software (Anthony, 2011). In this process, comparing formal morphemes such as particles and articles is not only irrelevant to the purpose of this study, but also, considering the grammatical differences between Korean and English, grammatical words were excluded from the analysis. Only content words, such as nouns and verbs, which carry meaning, were included in the analysis. Co-occurrence analysis was also conducted using AntConc. The co-occurrence range was set to within five words to the left and right of the target word. For each textbook, the words that co-occurred most frequently with the main concept of "force" were extracted and compared.

2.4. Text Network Analysis

As the goal of this study was to examine the scientific semantic network associated with force, it was necessary to extract the complex connections between the word "force" and other words within the text. To this end, a text network analysis method was used. Text network analysis is a method based on the linguistic variance hypothesis and is used to quantitatively analyze and visualize the relationship between the words that constitute a text (Newman, 2010; Steels, 2005). The quantitative information extracted from a text is valuable because the text reflects the meanings and conceptual structures shaped by the thought processes of individuals within a language-sharing community. By analyzing the relationships between words that are used together within a sentence or paragraph, it is possible to identify the patterns and structures formed by the interaction of individual and fixed attributes of key terms and concepts within the text (Anderson, 2002; Diesner & Carley, 2005). One of the greatest advantages of text network analysis is its ability to visualize the individual attributes of words embedded in a text and the relationships between them. Indicators that can be extracted through text network analysis include cohesion, centrality, and clusters. However, this study focused solely on centrality, as the aim was not to examine the attributes of individual texts but to extract the common semantic structures that underlie multiple texts (Borgatti & Brass, 2019). In text network analysis, centrality is divided into four types: degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality. This study focused exclusively on degree centrality (Freeman, 1979). These four types of centrality are used in text network analysis to highlight the importance of words from different perspectives. A word with high degree centrality is a key word in the text, frequently used and well-connected to other words. A word with high closeness centrality is advantageous for quickly activating key concepts, as it has a short semantic distance from other words. A word with high betweenness centrality often acts as a mediator, connecting different words within the text, while a word with high eigenvector centrality is strongly connected to other important words in the text (Bonacich, 1987). In this study, the network was visualized using the degree centrality values of the words to understand the overall connections between the words that make up the text. Additionally, betweenness centrality was referenced to explore the structural characteristics of the content.

In text network analysis, the network comprises nodes that represent each word and edges that represent the connection between nodes. In other words, every word was given a series of addresses, and the degree of connection between them was quantified. The more frequently two words are used together in the same sentence, the less the distance between the nodes representing the words and the thicker the edges. In the text network analysis, nouns, verbs, and adjectives were used. If two or more words were combined and used as a single scientific term, such as "net force," the combined words were linked under a bar and treated as a single word. After the refining process, the co-occurrence matrix between the words was created using the frequency of two words used in the same sentence. Network analysis and visualization were performed using Gephi 9.2.

3. Research Results

3.1. Words Used in Three Textbooks

The results of comparing the nouns and verbs used to teach the concept of force in the three textbooks showed that there were 89 common words between the textbooks from Korea, the United States, and Singapore (Table 2). As the average number of words used in each of the three textbooks was around 545, the results showed that approximately 16% of the words in each of the three textbooks were common to all. The proportion of the 89 common words in the textbooks was analyzed for each country. The analysis revealed that 18.0% of the total words in the Korean textbook, 14.2% in the U.S. textbook, and 17.3% in the Singaporean textbook consisted of these common words.

In other words, even if the country and language used to describe the concept of force were different, the essential words comprised around 16%. This 16% includes not only physics-specific conceptual terms but also everyday words used to explain those concepts. This indicates that the scientific semantic network constituting the concept of "force" includes both technical and everyday language, and that such components are shared across different languages and cultures. The remaining 84% of the words correspond to the words used differently by the three textbooks. This means that various linguistic expressions are used by the authors to explain same scientific concept. The use of various examples or metaphors, depending on who explains it, will also be reflected in the 84% word composition.

acceleration, act, action, analyze, appear, apply, balance, ball, call, car, case, cause, change, choose, condition, consider, continue, direction, discuss, distance, earth, event, example, exist, experience, express, fall, figure, find, force, friction, gravity, ground, hand, horizontal, include, increase, know, law, leave, line, magnet, magnitude, make, mass, meaning, measure, method, move, name, nature, net_force, Newton, newton_first_law, newton_second_law, newton_third_law, object, observe, opposite, point, press, problem, produce, pull, push, reach, reaction, relate, represent, result, right, run, section, situation, space, speed, stick, stop, string, table, think, time, turn, use, value, wall, water, weight, word

Table 2. Words that appeared in all three of the textbooks

As the 89 words presented in Table 2 are words that are commonly used in textbooks written in different countries or languages, they are the words most likely to comprise the scientific semantic network of the concept of force. The words in Table 2 include everyday words as well as scientific terms. This means that not only scientific terms, but also everyday words play an important role in implementing scientific concepts in real languages rather than in terms of the dictionary definition. Words lists like Table 2 are difficult to create in a deductive way.

Next, the proportion of the 89 common words within the entire text was examined. In the Korean textbook, the 89 words accounted for 41.6% of the total 2,078 tokens. In the U.S. textbook, they represented 42.4% of the 3,287 tokens, while in the Singaporean textbook, they made up 39.4% of the 1,847 tokens. This indicates that, on average, approximately 41% of the total text was consistent across the textbooks.

3.2. High Frequency Words

The words used in each of the three textbooks were arranged in the order of frequency, and the top 10 scientific terms were extracted and compared (Table 3). Seven of the top 10 scientific terms used in the three textbooks were shared across all three textbooks. These seven terms were “force,” “object,” “newton,” “acceleration,” “mass,” “motion,” and “direction” and can be seen as key terms that constitute the concept of force. The top 10 scientific terms accounted for 21.8% in Korea, 19.1% in the United States, and 21.1% in Singapore, with the percentages for all three textbooks being close to 20%. Given that the total number of words was between 500 and 600, it can be concluded that the percentage of these 10 terms as a proportion of all the words used was high and that the texts centered on these terms.

Korea		**U.S.A**		**Singapore**	
term	freq.(%)	term	freq.(%)	term	freq.(%)
force	147(7.1)	force	332(7.1)	force	130(7.0)
object	86(4.1)	object	136(4.1)	object	44(2.4)
newton	39(1.9)	friction	51(1.6)	resultant	44(2.4)
acceleration	32(1.5)	newton	36(1.1)	vector	33(1.8)
mass	31(1.5)	earth	35(1.1)	mass	31(1.7)
motion	29(1.4)	net_force	34(1.0)	motion	25(1.4)
reaction	28(1.3)	motion	31(0.9)	direction	23(1.2)
magnitude	27(1.3)	acceleration	28(0.9)	newton	23(1.2)
direction	23(1.1)	mass	27(0.8)	acceleration	21(1.1)
earth	12(0.6)	direction	19(0.5)	friction	17(0.9)

Table 3. Top 10 scientific terms in each three textbooks

Word frequency provides various insights. It can reveal the importance of a word within a text, the conceptual components it represents, and the overall characteristics of the text. Many texts exhibit the pattern of including a small number of high-frequency words and a large number of low-frequency words. This suggests that frequency information is a crucial basis for determining the priority of vocabulary instruction. The high-frequency words presented in Table 3, especially those common across the three countries, can be interpreted as the most important words to prioritize when teaching the concept of force.

In each of the three textbooks, the words that co-occurred within five words to the left and right of "force" were extracted and listed in order of frequency. The results showed that in all three textbooks, the words most frequently co-occurring with "force" were "object" and "action." The degree of co-occurrence to the left and right of "force" was similar, but it was slightly higher on the right. This pattern was consistently observed with both "object" and "action."

3.3. Comparison of Text Network

A text network analysis was conducted to see how words commonly used in the three textbooks related to and were connected in the text. Words that appeared two or fewer times were excluded to avoid overcomplicating results. The words were categorized into two groups: the first group consisted of words that were shared across all three textbooks, while the second group included words that appeared exclusively in individual textbooks. Figures 1-3 below are a visualization of text networks in the Korean, U.S., and Singaporean textbooks, respectively; here, a circle indicates a word and is called a node. The connecting lines between the circles represent the connection between words and are called edges. The size of each circle reflects how frequently the word was associated with others; larger circles indicate more frequent associations. The nodes shown in red indicate words shared across all three textbooks. 50 words among 89 are red.

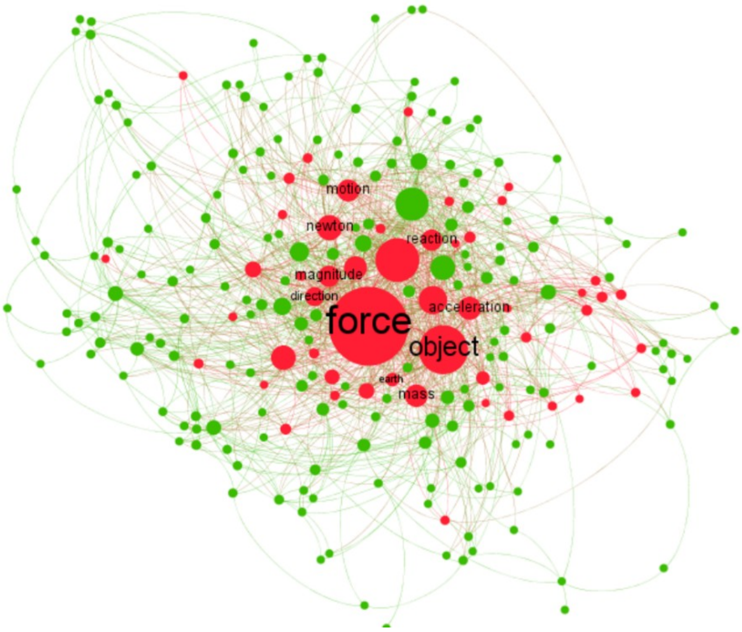

Figure 1. Text network of Korean textbook

In terms of the characteristics shown in the visualized text network analysis results in Figures 1-3, the node representing the word "force" in all three countries was the largest and was at the center of the network. This result supports the use of text network analysis to explore the subject of science texts and points to the potential for text network analysis methods to be used in the topical analysis of other scientific texts. Secondly, the red nodes tended to be larger and more centered than the other nodes. This phenomenon indicated that the common words in the three textbooks were often used in high frequency with importance in each text. Words close to force were more likely to form sentences within the text directly linked to the word "force" and relatively far from the force node. Furthermore, they were also more likely to act as intermediaries of connections with other words. Therefore, the tendency of red and large nodes to be located close to force could be an indicator that they are key words that directly connect with force to form the concept of force.

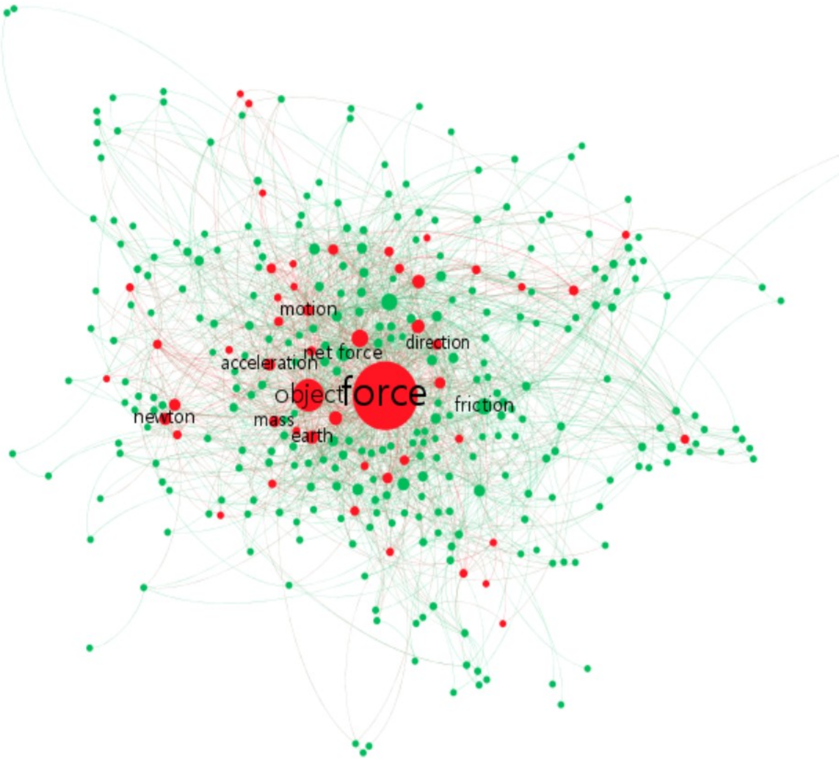

Figure 2. Text network of U.S. textbook

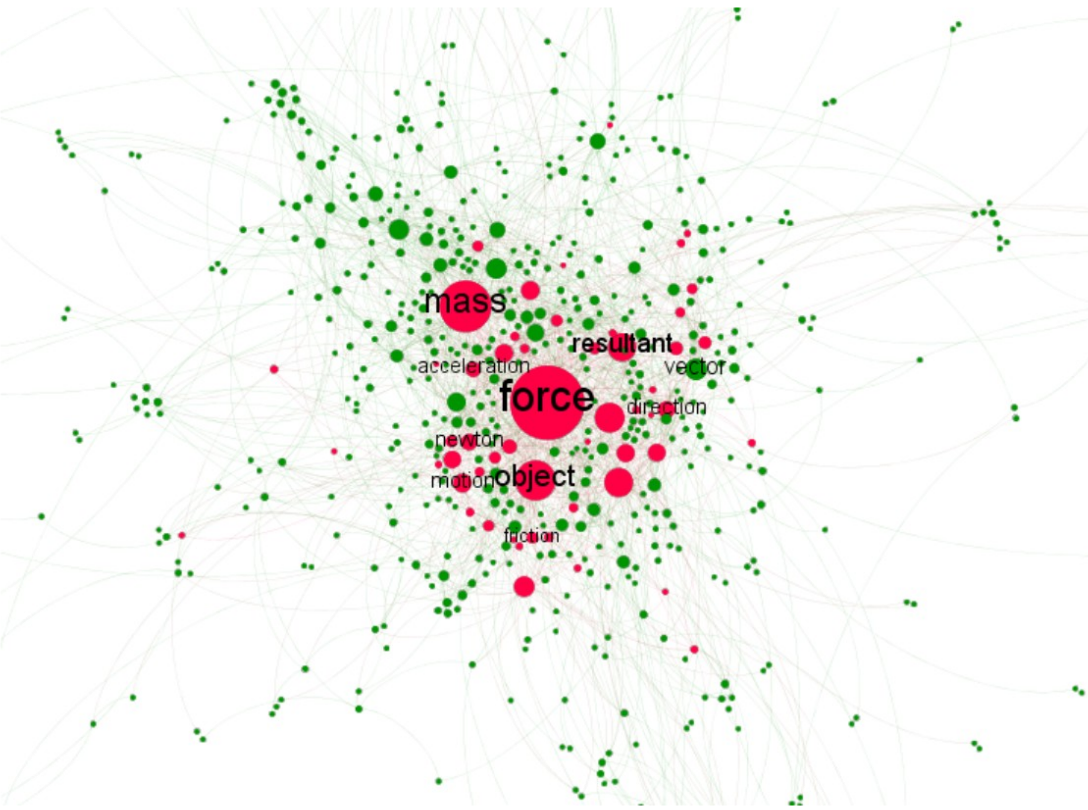

Figure 3. Text network of Singapore textbook

Next, the words with high betweenness centrality were examined. Words with high betweenness centrality often serve as intermediaries between other words in the text and frequently reveal context or situational elements (Yun, 2020b). The analysis of the betweenness centrality in the text networks of the three textbooks revealed differences across countries. In the Korean textbook, the word "person" had high betweenness centrality, while in the U.S. textbook, it was "car," and in the Singaporean textbook, "mass" emerged as the word with high betweenness centrality. This indicates that there are contextual differences in how force is described. In the Korean textbook, force is often explained in situations involving human actions, while in the U.S. textbook, it is frequently described in the context of a car in motion. In contrast, the Singaporean textbook tends to describe force in relation to mass, rather than specific situations involving objects or people. This suggests that the Singaporean textbook may employ more abstract descriptions compared to the textbooks from other countries.

3.4. Scientific Semantic Network about Force

Figure 4 depicts a visualization of relationships between words that were commonly used in the three textbooks. It is thought that the network presented in Figure 4 depicts the core structure of the scientific semantic network that constitutes the concept of force. The network in Figure 4 shows the words that constituted the concept of force and the connections between the words that are commonly organized in the minds of the writers of physics textbooks in Korea, the United States, and Singapore. This means that if experts in scientific concepts of force are asked to explain the concept of force to high school students, the words shown in Figure 4 are likely to appear in their descriptions.

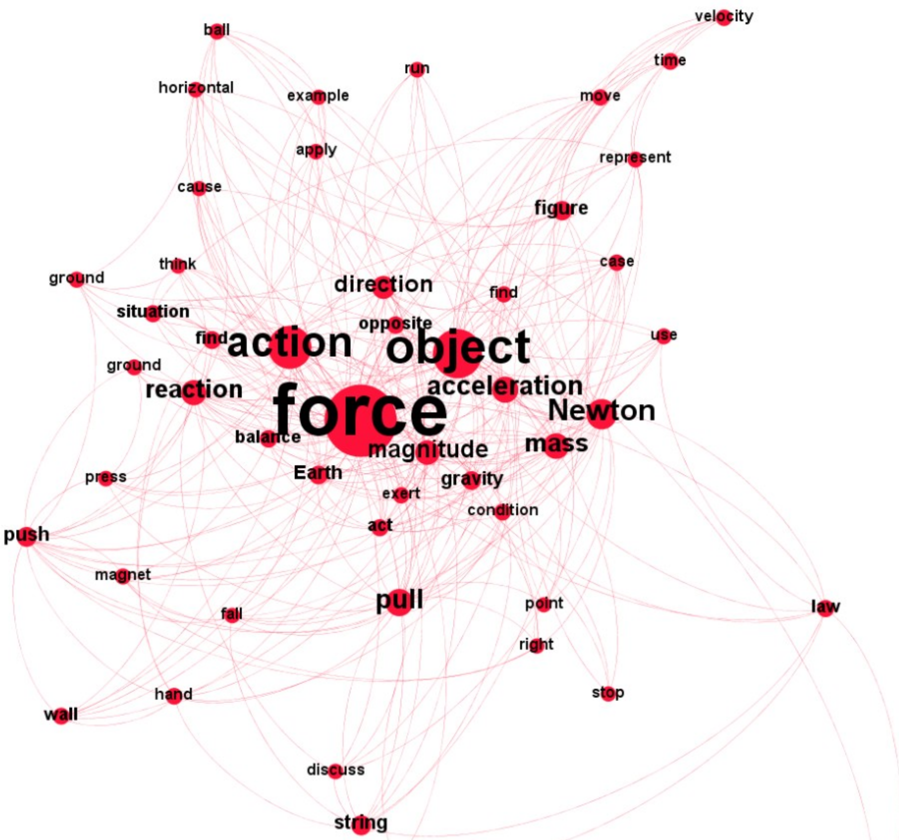

Figure 4. Visualization of relationships between common words

The words and the relations between them are different from the conceptual map commonly used in science education. Conceptual map mainly expresses conceptual hierarchical relations or inclusion relations among scientific terms. But the scientific semantic network represents the organization of the components that make up the scientific concepts of this term for a scientific term (Yun, 2020a). And this elemental organization will help enable natural and accurate implementation in terms of scientific knowledge when expressing the concept verbally.

In fact, fully articulating the scientific concept of "force" through language is far from straightforward. The definition of "force" found in dictionaries does not necessarily align with its meaning as a scientific concept. Moreover, it is difficult to determine the boundary between whether or not students have developed a scientific understanding of the concept in their cognition. In this sense, the word connection relationship in Figure 4 goes far beyond the dictionary definition of force. The network in Figure 4 is not a perfect or absolute conceptual structure; however, if high school physics students can be taught to explain force with the words and word connections shown in Figure 4, they are likely to also be able to conceptualize force. Thus, the network in Figure 4 is an empirical manifestation of the conceptual framework for force in the language of science.

4. Discussion

A particular language reflects the thoughts, culture, and values of the group that shares it. The language of science reflects the thought processes of a community that shares a scientific knowledge system, transcending specific nations, cultures, and linguistic forms. The results of this study clearly demonstrate this. While both the United States and Singapore use English, cultural differences exist between them, and Korea uses an entirely different language. Despite these differences, the science textbooks from the three countries showed significant commonalities in the way scientific concepts were described, and these commonalities were also evident in the quantitative analysis.

The language of science is inherently unfamiliar to both native and non-native speakers. While the challenges faced by learners who must study science in a language other than their native tongue are often discussed, these difficulties are not solely due to the differences in linguistic forms. They also stem from the intrinsic unfamiliarity and distinctiveness of scientific language itself. Therefore, in order to support learners in mastering science, it is crucial to focus on the inherent characteristics of scientific language that transcend national, cultural, and linguistic boundaries. This study was grounded in the assumption that the essence of scientific language is universally embedded, regardless of the country, culture, or language in use. By analyzing the elements commonly extracted from various texts, the study aimed to identify the fundamental characteristics of scientific language, thereby revealing the essential nature of science itself.

The scientific semantic network extracted from this study corresponds to the ideal target point that the mental semantic network of students should reach. If the mental semantic network for 'force' becomes similar to Figure 4 in the minds of students, this student has a concept structure similar to that of an expert on 'force'. Therefore, the network in Figure 4 extracted as a result of this study can be regarded as a visualization of what we usually call a 'scientific concept'. The mental semantic network of students at the beginning of learning the concept 'force' may be significantly lacking in elements or connected differently compared to those in Figure 4. Lack of elements can be seen as a Pseudo-concept (Vygotsky, 1962) condition, an incomplete concept for students in the conceptual development process. And if the connection between the components is different from what is accepted among experts, it can be seen as a misconception (Yun, 2020a). In fact, when we looked into the mental semantic network of students through word association tests, it was proven that the concept understanding was low when the structure was different from that of experts (Yun, 2020a). Therefore, when teaching scientific concepts, it is necessary to clearly base the scientific semantic network as shown in Figure 4, and to find a strategy to implement it verbally. On the other hand, the process of passing on the scientific semantic network to students is very implicit and potentially happening. If you look at the process of mother tongue acquisition, you would not have explicitly learned the meaning of all the words we currently use and the grammar of the sentences we use. Nevertheless, we speak our native language almost perfectly and implicitly share the way of thinking, culture, and values latent in our native language. It's just that fluently speaking native speakers have led to language acquisition implicitly (Miller, 1996). Therefore, in order to ensure that students acquire the scientific concept of 'force' accurately, the network in Figure 4 should be implicitly but fully exposed in the language of textbooks or teachers' discourse. This is a different issue from encouraging students to understand the meaning of scientific sentences by increasing the readability of the language used by teachers in physics classes, or sentences used in items for physics assessment (Cromley, Snyder-Hogan & Luciw-Dubas, 2010; Höttech, Henke & Rieß, 2018). The scientific semantic network shown in Figure 4 corresponds to something that students should remain in their mind after forgetting what the teacher said or the individual sentences presented in the textbook. This is in the same context as Chomsky (1965) suggested in the language acquisition process, which supports the researchers' view that science learning is science language learning (Darian, 2003; Maskill, 1988).

5. Conclusions

In the present study, we extracted text on the concept of force from physics textbooks from Korea, the United States, and Singapore to identify common linguistic phenomena. The results of the study showed that the three textbooks shared 89 words, which was around 41% of text in each textbook, despite differences in language and culture. These words could be considered as key words that constitute a scientific knowledge system of force that encompasses the country and language. Its value lies not so much in providing useful explanations of the concepts students should learn, but in explicitly revealing the core conceptual framework that underpins what they are expected to learn. Secondly, the ratio of the top 10 scientific terms to the total text was approximately 20% and it was similar for all three textbooks. This suggests that the linguistic structure of the three textbooks was similar, which could indicate that scientific language has a universality that transcends different countries and languages. Thirdly, through text network analysis, we extracted a scientific semantic network that constituted the concept of force shared by the three textbooks. Below, we discuss the implications of the scientific semantic network extracted in this study in terms of physical education and practical ways of implementing the findings of this study.

Firstly, the scientific semantic network enables the implementation of a linguistic strategy for teaching science-related concepts. From a cognitive linguistic perspective, science teaching can be seen as encouraging students' mental semantic network to be organized similarly to the scientific semantic network utilized by experts. In view of the importance of having an ideal structural model to illuminate the structure of cognitive connectivity (Moreira & Santos, 1981), the scientific semantic network extracted in the present research can be considered an ideal model for teaching "force" concepts. The specific words shown in Figure 4 and the relationship between them can be used directly in linguistic strategies for teaching scientific concepts. For example, an activity may be used to create a sentence or paragraph by presenting some of the 50 words shown in the network in Figure 4. This could lead students to organize a scientific semantic network of force by enabling them to use 50 words only to form sentences associated with force.

The scientific semantic network also facilitates the development of new evaluation models for scientific concepts. To date, methods for identifying whether students understand scientific concepts involve allowing them to solve problems associated with physical phenomena that emerge in the real world or in imagined scenarios. These evaluation methods are often presented in the form of multiple-choice items. However, the results of these evaluations have clear limitations in terms of revealing the extent to which a student has understood a concept. Even if a student scores 70 out of 100 points on a concept test, it cannot be interpreted that the student understands 70% of a scientific concept. The results of this study allow for the introduction of an evaluation method that enables students to freely and fully describe concepts using particular scientific terms. The scientific semantic network in the present study could be an ideal model for evaluating students' responses, because it offers a clear structure that forms a concept used by experts in conjunction with a specific country or language. The degree of correspondence between the response described by students and the scientific semantic network can provide important tools for assessing the completeness or accuracy of a student's acquisition of a concept. In addition, the presentation of these ideal models enables automatic computer assessment of long sentences described by students, which can dramatically improve the time and effort required for grading and the validity of the essay type assessment results.

Thirdly, scientific semantic network enables control over the quality of a teacher's language used in the classroom. In the present study, textbooks from three countries shared around 16% of their words, and these words were considered core words that constituted the scientific concept of force. Therefore, it is important not to omit these 16% of words from conceptual teaching, which should be fully addressed in the teacher's language. However, there is often a difference between the language used in textbooks and teachers' language in classroom, and important words are often omitted from teachers' language. In addition, research by Yun and Park (2018) emphasize that such problems could be even greater depending on the teachers' specific major. Thus, the network in Figure 4 can serve as a model for quality controlling and ensuring that teachers implement a variety of rich explanations in their classes, while also ensuring that 16% of the core conceptual structures is not missing or incorrectly implemented. Therefore, the network in Figure 4 can serve as a model for quality management to enable teachers to implement diverse explanations in their classes.

However, the devised model does have some limitations. As one textbook from three different countries was studied, it cannot be concluded that the same phenomenon occurs across all other textbooks. In addition, it is difficult to regard Figure 4 as a complete form of a scientific concept because the scope of scientific concepts varies according to the school level. However, the linguistic phenomena commonly seen in texts written in different countries and languages are meaningful, and the research methods presented in this study may contribute to the study of scientific languages in the future.

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