MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2024, 20(7), em2479
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/14763

Examining the cognitive structure of elementary school students regarding science, energy sources, and health using the word association method

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Received 08 March 2024 ▪ Accepted 26 May 2024

Abstract

We explored the cognitive structure of students in grade 1-grade 4 using word association in three topics (science, energy sources, and health) with six-six keywords (stimulus words) per topic. Based on the common associations given to the stimulus words, we calculated the relatedness coefficient for the stimulus word pairs. This was used to draw a cognitive structure, the conceptual network, characteristic of each group of learners. We found that the verbal version of the word association test is suitable for studying the cognitive structure of young schoolchildren. The typical conceptual network of the student groups shows a strong correlation with the knowledge structure of experts in grade 4 (in all three topics), as well as in grade 1 and grade 3 (in the topic of health). Using word association tests, we have been able to demonstrate that the number and strength of connections in the conceptual networks for groups of learners increases with the learners' grade and their everyday experience of the topic.

Keywords: cognitive structure, word association, elementary school students, science, energy sources, health

INTRODUCTION

In recent decades, we have seen many attempts to introduce science, technology, engineering, and mathematics (STEM) in pre- and primary school education (Larkin & Lowrie, 2023). But these studies mainly focus on the methodology of introduction and do not, or hardly, address the impact of STEM introduction on students' conceptual development and cognitive structure. Exploring the cognitive structure of learners and groups of learners and monitoring changes in the cognitive structure is essential for planning an effective teaching-learning process. Although there are well-known methods for exploring cognitive structure, there is a lack of scientific research on their applicability in pre- and primary school education (Tsai & Huang, 2002). Thus, our work is incomplete in that we provide an example of the applicability of one of these methods, free word association, to primary school students in grade 1-grade 4.

The general assumption is that the cognitive structure is modeled as an associative network (for example Tsai & Huang, 2002). The cognitive structure of individual learners can be visualized by plotting a graph based on their responses, while a network representing the cognitive structure of a group of learners can be generated by averaging the individual responses of the group members.

There are several methods available for examining cognitive structure. Concept mapping can be used not only for individual examinations but also for collective analyses (for example Taber, 2002). Knowledge space theory offers opportunities not only for group knowledge structure examinations but also for optimizing examination and educational processes (for example Doignon & Falmagne, 1999; Taagepera et al., 1997; Tóth, 2007). Both individual and group cognitive structure examinations are possible using the word association method (for example Chachapuz & Maskill, 1987; Hovardas & Korfiatis, 2006; Malmos et al., 2017; Nakiboglu, 2008; Tóth & Sója-Gajdos, 2012). Because of its simplicity and its applicability in the classroom, the word association method was chosen at the beginning of our research and will be described in detail below.

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Contribution to the literature

- In our study, we have shown that the verbal version of the word association test can also be used to explore the cognitive structure of students.
- We have shown that the verbal version of the word association test can also be used to explore the cognitive structure of groups of students.
- This opens up the possibility of extending word association tests to learners who have difficulties in reading and writing.

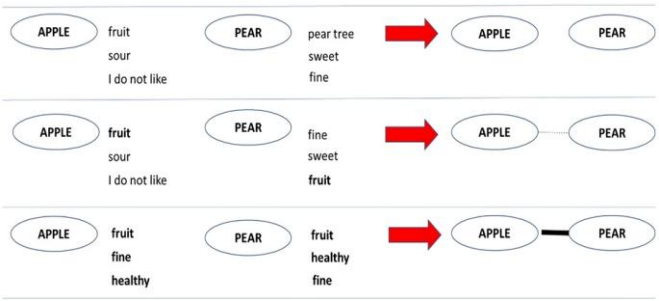

Figure 1. Basis of examination of knowledge structure using word association test: More common associates–Stronger connection (Source: Authors' own elaboration)

Word Association Test

The word association test began to be used in the 1980s, especially in natural sciences, to explore the cognitive structure of students (Isa & Maskill, 1982; Chachapuz & Maskill, 1987). It is suitable for both individual and group cognitive structure testing. The essence of the method is that by applying the key concepts of a certain topic, such as stimulus words, we examine what other words the pupil associates with during a given period. The strength of the relationship between each stimulus word can be inferred from the common response words (**Figure 1**). Due to its simplicity and the little time demand of testing, the word association test can also be used in classes.

Most Important Publications Related to Investigated Topics

In our research, we examined key concepts, such as stimulus words in three topics: science, energy sources, and health. Therefore, we will briefly review word association studies related to the topics of science and energy resources (unfortunately, we could not find any such studies related to the topic of health).

Armagan (2015) examined the change in the cognitive structures of 6th and 7th graders concerning the concepts of science ('science', 'scientific knowledge', 'scientific method', 'scientist', 'research', 'project', 'experiment', and 'laboratory') through word association test. The results obtained before and after a short extracurricular project showed that the number of student associations increased from pre-test to post-test. It was found that the highest number of associations was made for the concept 'science', while the number of responses for the 'scientific method' concept was less than others. The author used only the total number of common associations to characterize the strength between the keywords. A very strong connection was found between 'laboratory' and 'experiment' in the pre-test, and besides 'scientist'–'science'–'research'–'project' in the post-test. It was determined that the words associated with concepts in the pre-test were commonly used words by students in everyday life. Contrarily, the words associated with the same concepts in the post-test were words that were more closely relevant to key concepts.

Gulacar et al. (2015) explored the changes in students' understanding of the scientific method using word associations. Students from grades 4, 5, and 8, as well as first-year college students, were tested with stimulus words: 'research', 'project', 'problem', 'experiment', 'data collection', 'hypothesis', 'dependent variable', 'observation', 'writing report', and 'science fair'. The authors calculated relatedness coefficients (RCs) and the 20 strongest relationships were mapped for each grade. They found that central concepts were 'data collection' and 'hypothesis' (grade 4), 'data collection' and 'science fair' (grade 5 and grade 8), and 'data collection' and 'experiment' (first-year students). Among others they established that 'science fairs have a strong influence on students' conceptions about the scientific process', however, 'students need to know the central role that experimentation takes in the scientific process'.

Tóth and Sója-Gajdos (2012) studied Hungarian 7th to 12th graders' cognitive structure related to energy sources. They used six stimulus words: 'energy source', 'renewable energy sources', 'non-renewable energy sources', 'coal', 'crude oil', and 'nuclear energy'. They found that the complexity of the cognitive structure increased by from grade 7 to grade 12. Their results also showed that cognitive structure complexity depended on the type of school: trade school < vocational school < secondary grammar school. There was a very strong connection between 'crude oil' and 'non-renewable energy sources', however, 'nuclear energy' was either isolated or linked to 'renewable energy sources' in the typical cognitive structures of students' groups of different grades and school types.

Malmos et al. (2017) used a word association test to assess the cognitive structure of renewable energy sources (keywords: 'renewable energy', 'energy saving',

Table 1. Stimulus words for three topics (with two-two students per topic & class, with a maximum response time of one minute for each stimulus word)

Science	Energy sources	Health
What comes to mind when you hear the word ...?	What comes to mind when you hear the word ...?	What comes to mind when you hear the word ...?
scientist	crude oil	doctor
science	natural gas	disease
research	coal	cure
explanation	firewood	healthy diet
experiment	solar panel	health
observation	renewable energy source	medicine

'power station', and 'heating') among Hungarian 4th and 7th graders. They found more complex cognitive structures for 7th graders, city learners, and boys. Markóczi et al. (2019) studied primary (grade 4 and grade 7), and secondary (grade 11) school students' knowledge related to renewable energy and some of its influencing factors. Cognitive structure of grades was similar with associations related to solar, water, and wind.

Aims & Hypotheses

In our research, we conducted a cross-sectional study on six-six concepts of three topics (science, energy sources, and health) as stimulus words among students in grade 1-grade 4 using word association to explore the typical cognitive structure of the students' groups. Due to the reading and writing difficulties of elementary school students, we decided to take the word association test orally. In conducting this, we relied on our previous experience (Daru & Tóth, 2013) among pre-school students. Our hypotheses were, as follows:

- **H1.** The verbal form of the word association test is suitable for assessing the knowledge structure of elementary school students.
- **H2.** The number and strength of associations between concepts in the knowledge structure of students increases from grade 1 to grade 4.
- **H3.** In the 3rd grade, at the start of the subject of environmental studies, there is a leap in the knowledge structure of grade 1-grade 4. students related to the examined concepts.
- **H4.** For concepts related to pupils' everyday life, the concept network contains fewer isolated elements than abstract concepts.
- **H5.** Despite the conceptual development, the typical cognitive structure of groups of learners resembles that of experts up to grade 4.

MATERIALS & METHODS

Sample

Nearly 400 grade 1 to grade 4 (aged: seven to 10) students from 62 classes of nine schools in Eastern Hungary participated in the survey. For all classes, the 6 students (two-two per topic) who participated in the oral word association test were randomly selected. The distribution of the sample is given in **Table A1** in **Appendix A**. Before data collection, the teachers obtained parental consent for the children to participate in the survey anonymously.

Measuring Instrument

Previously, six-six stimulus words (concepts) have been compiled under three topics (science, energy, and health) (**Table 1**). A list of these was used by the teachers. The order of the concepts in the list varied from school to school.

Data Collection

The measurements (data collection) were conducted by the teachers instructing the students. They were prepared through several online discussions.

The measurement took place between February and April 2023. The oral data collection was recorded by the teachers in audio files and sent to us for evaluation. Additionally, we requested that they fill out a background questionnaire for each student–marked with an appropriate code–(the student's gender, grade level, relationship to the school, social circumstances, etc.).

In total, we received 390 audio recordings and an equal number of student data sheets. This amounted to 29-35 audio recordings per grade level and topic.

Data Processing

Student responses were words, phrases, and sometimes complete sentences. From the sentences, words with independent meanings were extracted (nouns and conjunctions were excluded from the analysis) and entered into the Excel sheet in the order of their occurrence. A word could only be used once and a maximum of 15 associations per stimulus word were allowed. An example of continuous text transformation is given, as follows:

> Teacher: 'Mi jut eszedbe arról a szóról, hogy tudós?' ['What comes to mind when you hear the word: scientist?']

Table 2. An example for calculating RC between stimulus words

Stimulus word	Rank
Stimulus word (A)	
SCIENTIST	5
clever*	4
discover**	3
invention	2
famous	1
Stimulus word (B)	
SCIENCE	5
hard	4
discover**	3
clever*	2

Note. $RC = \frac{\bar{A}\cdot\bar{B}}{\sum n^2-1} = \frac{4\times2+3\times3}{5^2+4^2+3^2+2^2+1^2-1} = 0.31$.

> Student (grade 1): 'Aki feltalálta a vizet, az olajat meg a gázolajat, … meg a benzint, … meg aki szokott laborban mérni' ['The one who invented water, oil, gas oil, … and gasoline, … and the one who used to measure in the lab'].

Associations extracted from the answer: feltalál, víz, olaj, gázolaj, benzin, labor, mér [invent, water, oil, gas oil, gasoline, measure, lab].

Then, we compared the associations obtained for different stimulus words, and the inflected forms were transcribed to the corresponding base word (Hovardas & Korfiatis, 2006).

These associations were used to calculate RC between each pair of stimulus words (Cardellini, 2008; Garskof & Houston, 1963). An example of calculating RC is shown in **Table 2**.

RC is defined by Eq (1), as follows:

$$RC = \frac{\bar{A}\cdot\bar{B}}{\sum n^2-1}, \quad (1)$$

where $\bar{A}$ represents the rank order of occurrence of words under stimulus word A, which are shared in common with stimulus word B, and $\bar{B}$ represents the rank order of words under stimulus word B, which are shared in stimulus word A; and n represents the number of words in the longer list (the maximum value of the rank order).

Let's see the example of two selected stimulus words, scientist (A) and science (B) (**Table 2**). In this case n=5, and the common words are clever (rank: 4 and rank=2; product: 4x2=8); discover (rank: 3 and rank=3; product: 3x3=9).

Based on the data-set containing the means of RCs for each pair of stimulus words the cognitive structure was drawn as a graph showing stimulus words and different lines between them. The type of line indicates the strength of connection. We used four different cut-off points in the notation of the value of RC (**Table 3**).

Table 3. Cut-off points & notations used in graphical representation of cognitive structure

RC	SC	Notation
0.00-0.04	NC	
0.05-0.09	Weak	
0.10-0.19	Medium	
0.20-0.39	Strong	
0.40-1.00	Very strong	

Note. SC: Strength of connection & NC: No connection

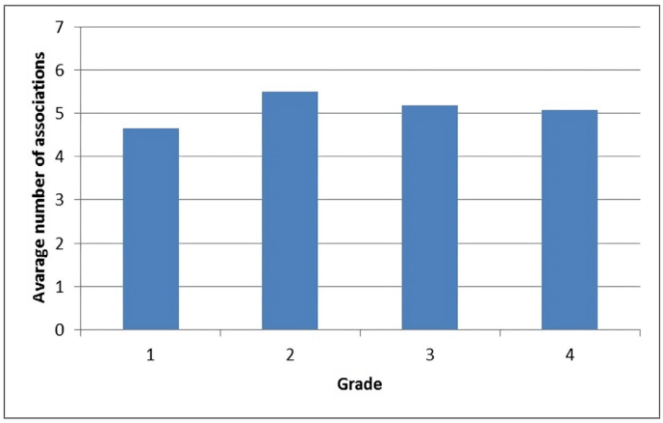

Figure 2. Average number of associations received in 'science' for different grades (Source: Authors' own elaboration)

In this paper, we will only present and analyze the conceptual networks. The content analysis of the associations is in progress.

Experts' Cognitive Structures

In order to establish the expert cognitive structure, 10 academics (computer scientist, chemist, geographer, doctor, engineer, mathematician, and biologist) were asked to rate the strength of the relationship between the stimulus words on a scale of zero to three (zero is no relationship and three is very strong relationship).

The average of these was used to obtain the strength of the links in the expert cognitive structure, which is presented in **Table A2** in **Appendix A**.

RESULTS

Topic 'Science'

A moderate number of associations were obtained for the 'science' topic stimulus words (see **Table A2** in **Appendix A** for detailed data). As can be seen in **Figure 2**, the 1st graders gave slightly fewer associations than the 2nd-4th graders.

Figure 3 shows the average number of associations received for each stimulus word. Most associations were made with the stimulus word 'observation'. This is not surprising, as the everyday meaning of this term is well-known to students. However, the least number of

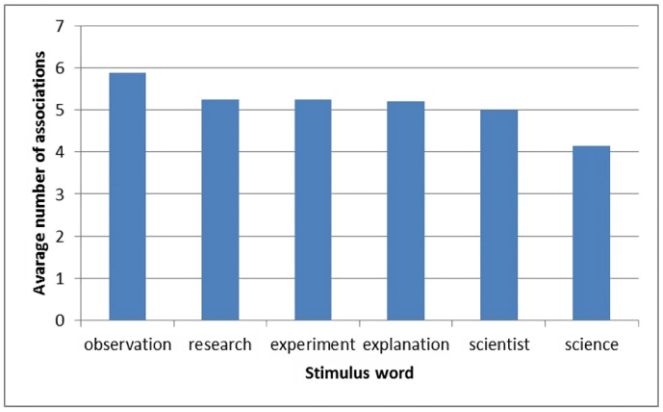

Figure 3. Average number of associations received in 'science' for different stimulus words (Source: Authors' own elaboration)

Table 4. Correlation between students groups as well as experts in terms of RCs in 'science'

Science	Grade 1	Grade 2	Grade 3	Grade 4	Experts
Grade 1	1	0.949**	0.793**	0.874**	0.457
Grade 2		1	0.924**	0.950**	0.487
Grade 3			1	0.910**	0.484
Grade 4				1	0.583*
Experts					1

Note.*p<.05 & **p<.01

associations was for science. This seems to be the least known of the six key concepts.

RCs between the six concepts of the 'science' topic for different grades are presented in **Table A3** in **Appendix A**.

As can be seen from **Table 4**, there is a very strong, significant correlation between the student groups in terms of RCs.

We show the typical cognitive structures of pupils at different grades. In the first and second classes, only 'scientist', 'science', and 'experiment' form a relatively loose unit, the other three concepts ('observation', 'explanation', and 'research') remain isolated elements.

Figure 4 shows conceptual networks between the stimulus words in the 'science' characteristic for the 1st graders (cut-off points: RC=0.10; 0.05).

Figure 5 depicts conceptual networks between the stimulus words in the 'science' characteristic for the 2nd graders (cut-off points: RC=0.10; 0.05).

In grade 3 and grade 4, the six concepts form a loosely connected network, suggesting that a qualitative change in the cognitive structure of students occurs in grade 3. This is probably due to the impact of the environmental science subject starting in grade 3.

Figure 6 shows conceptual networks between the stimulus words in the 'science' characteristic for the 3rd graders (cut-off points: RC=0.10; 0.05).

Figure 7 shows conceptual networks between the stimulus words in the 'science' characteristic for the 4th graders (cut-off points: RC=0.10; 0.05).

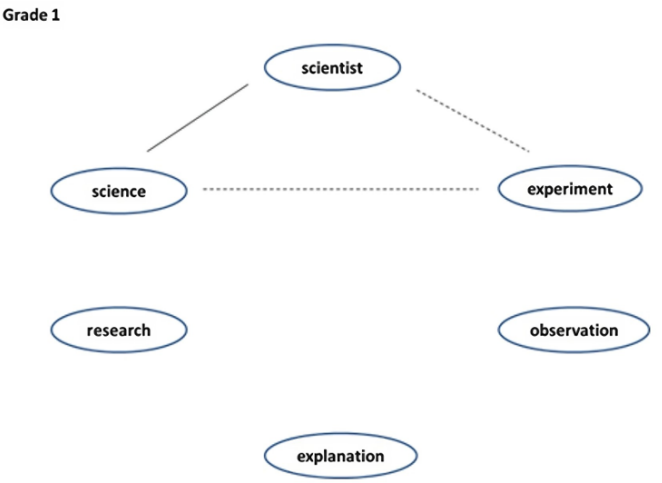

Figure 4. Conceptual networks between stimulus words in 'science' characteristic for the 1st graders (cut-off points: RC=0.10; 0.05) (Source: Authors' own elaboration)

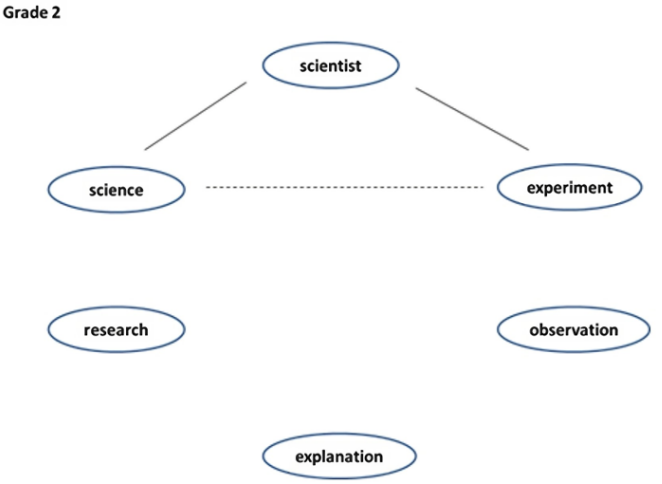

Figure 5. Conceptual networks between stimulus words in 'science' characteristic for the 2nd graders (cut-off points: RC=0.10; 0.05) (Source: Authors' own elaboration)

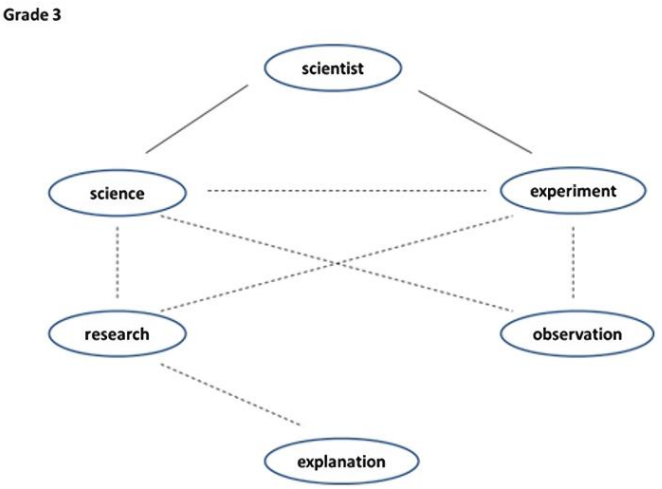

Figure 6. Conceptual networks between stimulus words in 'science' characteristic for the 3rd graders (cut-off points: RC=0.10; 0.05) (Source: Authors' own elaboration)

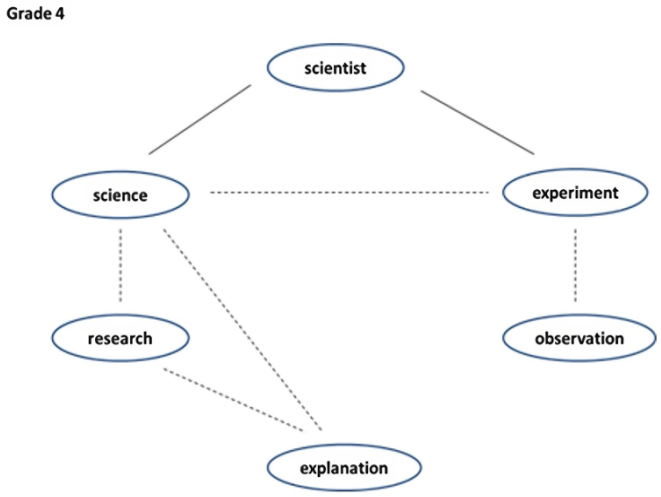

Figure 7. Conceptual networks between stimulus words in 'science' characteristic for the 4th graders (cut-off points: RC=0.10; 0.05) (Source: Authors' own elaboration)

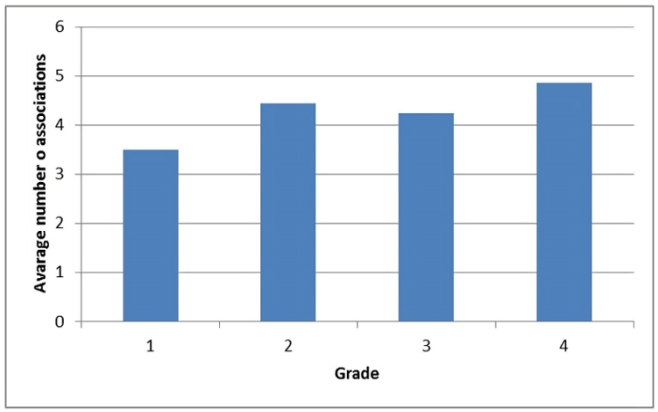

Figure 8. Average number of associations received in 'energy sources' for different grades (Source: Authors' own elaboration)

While the central concept in the characteristic cognitive structure of the 1st and the 2nd graders is the 'scientist', for the 3rd and the 4th graders 'science' becomes the central concept.

As a result of the gradual development, the cognitive structure of the 4th grade students already shows a strong, significant correlation with that of the experts (**Table 4**).

Topic 'Energy Sources'

Of the three topics examined, the 'energy sources' received the fewest associations (**Table A4** in **Appendix A**). These concepts seem to be the least familiar to young schoolchildren. There is a marked increase in the number of associations in the 2nd and the 4th grades (**Figure 8**).

The most associations were with 'firewood', 'solar panel', and 'renewable energy source', while the least were with 'crude oil' and 'natural gas' (**Figure 9**). These last two were so unfamiliar to the students that several of them even made a comment about them.

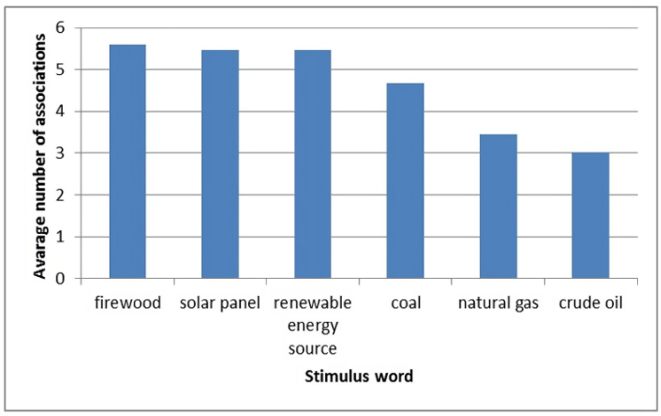

Figure 9. Average number of associations received in 'energy sources' for different stimulus words (Source: Authors' own elaboration)

Table 5. Correlation between students groups as well as experts in terms of RCs in 'energy sources'

Energy	Grade 1	Grade 2	Grade 3	Grade 4	Experts
Grade 1	1	0.936**	0.897**	0.654**	0.081
Grade 2		1	0.935**	0.691**	0.127
Grade 3			1	0.777**	0.224
Grade 4				1	0.671**
Experts					1

Note. ES: Energy sources; *p<.05; & **p<.01

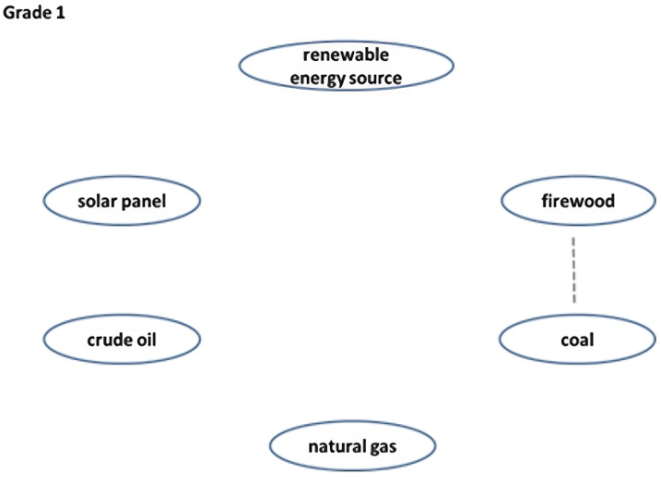

Figure 10. Conceptual networks between stimulus words in 'energy sources' characteristic for the 1st graders (cut-off points: RC=0.10; 0.05) (Source: Authors' own elaboration)

RCs between the six concepts of the 'energy sources' topic for different grades are presented in **Table A5** in **Appendix A**.

Here too, there is a strong or very strong significant correlation between the groups of students in different grades (**Table 5**).

We show the typical cognitive structures of pupils in different grades. In grade 1 and grade 2, only 'firewood' and 'coal' are weakly connected, all other concepts appear as isolated elements in the cognitive structure.

Figure 10 depicts conceptual networks between the stimulus words in the 'energy sources' characteristic for the 1st graders (cut-off points: RC=0.10; 0.05).

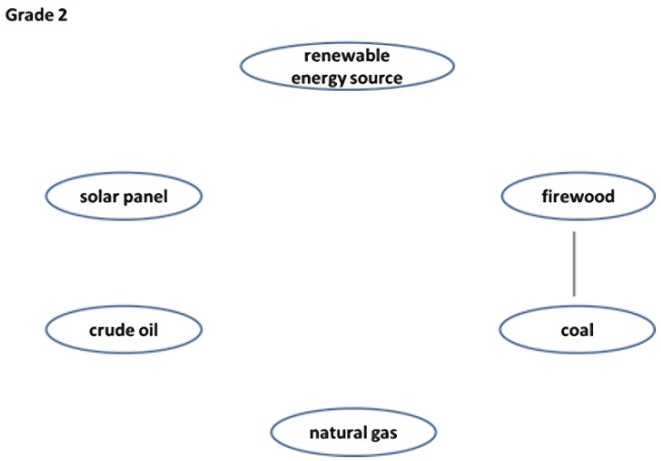

Figure 11. Conceptual networks between stimulus words in 'energy sources' characteristic for the 2nd graders (cut-off points: RC=0.10; 0.05) (Source: Authors' own elaboration)

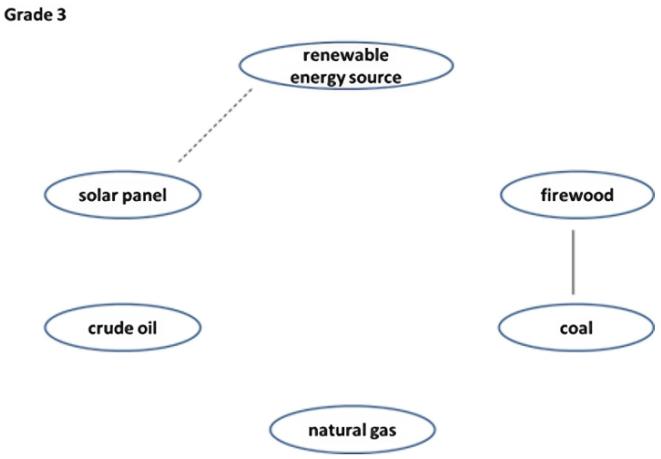

Figure 12. Conceptual networks between stimulus words in 'energy sources' characteristic for the 3rd graders (cut-off points: RC=0.10; 0.05) (Source: Authors' own elaboration)

Figure 11 shows conceptual networks between the stimulus words in the 'energy sources' characteristic for the 2nd graders (cut-off points: RC=0.10; 0.05).

In the 3rd grade, another weak link between 'solar panel' and 'renewable energy source' appears. It can be seen that for grade 1-grade 3 students, everyday experiences (wood and coal fires, solar panels on rooftops) shape the cognitive structure.

Figure 12 shows conceptual networks between the stimulus words in the 'energy sources' characteristic for the 3rd graders (cut-off points: RC=0.10; 0.05).

However, in the typical cognitive structure of the 4th graders, two isolated groups can be observed: the 'solar panel' with the connected 'renewable energy source', and the block containing fossil fuels ('crude oil', 'natural gas', 'coal') and 'firewood'. The connections are still weak and the link between 'firewood' and 'renewable energy source' is missing.

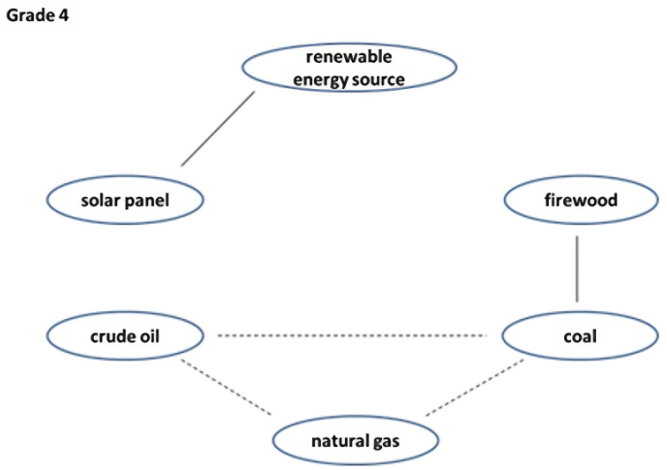

Figure 13. Conceptual networks between stimulus words in 'energy sources' characteristic for the 4th graders (cut-off points: RC=0.10; 0.05) (Source: Authors' own elaboration)

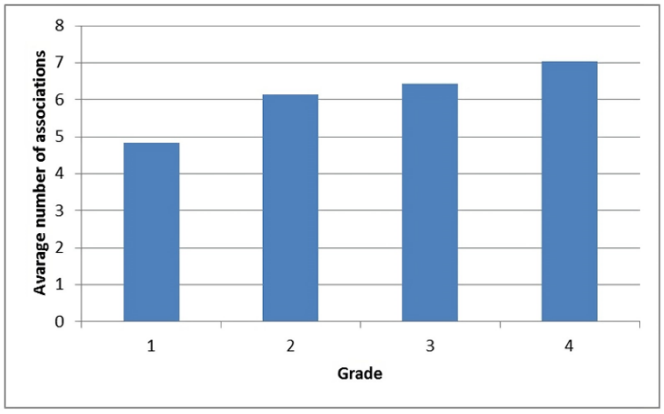

Figure 14. Average number of associations received in 'health' for different grades (Source: Authors' own elaboration)

Figure 13 shows conceptual networks between the stimulus words in the 'energy sources' characteristic for the 4th graders (cut-off points: RC=0.10; 0.05).

As a result of the leap in development in grade 4, there is a strong, significant correlation between the cognitive structure of the 4th graders and the experts (**Table 5**).

Topic 'Health'

As expected, 'health' was the topic with the most associations (**Table A6** in **Appendix A**). These concepts seem to be the most familiar to young pupils. The average number of associations increases steadily with grade, but the biggest increase is in the 2nd grade (**Figure 14**). The most associations were obtained for 'healthy diet', 'doctor', and 'disease', while the least was with 'cure' (**Figure 15**).

RCs between the stimulus words of the 'health' topic for different grades are presented in **Table A7** in **Appendix A**. **Table A8** in **Appendix A** shows means of

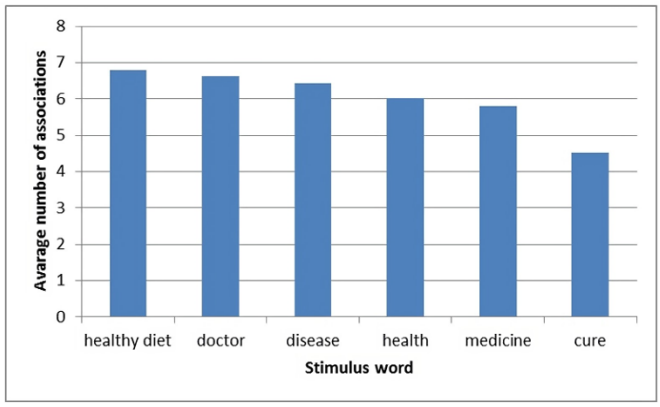

Figure 15. Average number of associations received in 'health' for different stimulus words (Source: Authors' own elaboration)

Table 6. Correlation between students groups as well as experts in terms of RCs in 'health'

Health	Grade 1	Grade 2	Grade 3	Grade 4	Experts
Grade 1	1	0.920**	0.908**	0.974**	0.522*
Grade 2		1	0.935**	0.934**	0.486
Grade 3			1	0.916**	0.594*
Grade 4				1	0.553*
Experts					1

Note. *p<.05 & **p<.01

RCs between stimulus words in the 'health' for different grades.

For 'health', there is a very strong, significant correlation between the typical cognitive structure of each grade (**Table 6**).

We show the characteristic cognitive structures of students at different grades. In contrast to the previous two topics, the cognitive structures obtained for the 'health' topic are very rich in relations. Students have knowledge and experience of almost all these concepts. In the 1st grade, two groups of concepts can still be observed, separated from each other.

Figure 16 shows conceptual networks between the stimulus words in the 'health' characteristic for the 1st graders (cut-off points: RC=0,20; 0.10; 0.05).

In the 2nd grade, these two groups are linked through the concept of 'medicine'. **Figure 17** shows conceptual networks between the stimulus words in the 'health' characteristic for the 2nd graders (cut-off points: RC=0,20; 0.10; 0.05).

In the 3rd grade this cognitive structure is somewhat loosened (**Figure 18**), however in the 4th grade, a relationship-rich structure emerges again, although it lacks the 'doctor'–'health' relationship (**Figure 19**).

Figure 18 depicts conceptual networks between the stimulus words in the 'health' characteristic for the 3rd graders (cut-off points: RC=0,20; 0.10; 0.05).

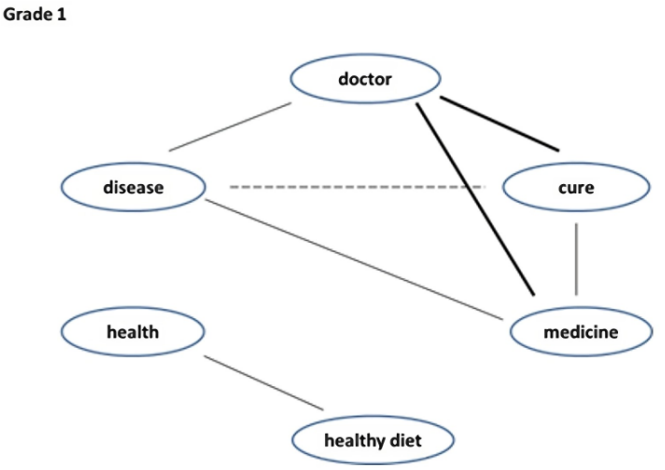

Figure 16. Conceptual networks between stimulus words in 'health' characteristic for the 1st graders (cut-off points: RC=0,20; 0.10; 0.05) (Source: Authors' own elaboration)

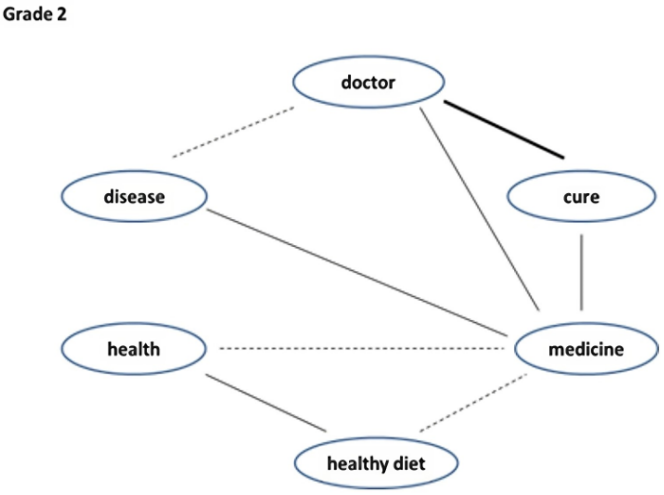

Figure 17. Conceptual networks between stimulus words in 'health' characteristic for the 2nd graders (cut-off points: RC=0,20; 0.10; 0.05) (Source: Authors' own elaboration)

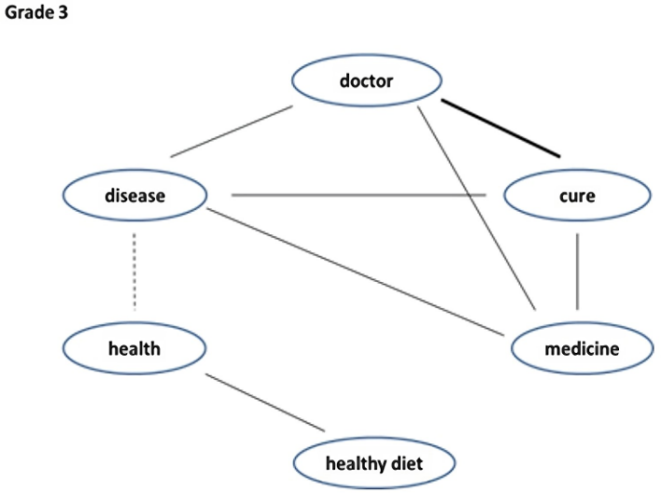

Figure 18. Conceptual networks between stimulus words in 'health' characteristic for the 3rd graders (cut-off points: RC=0,20; 0.10; 0.05) (Source: Authors' own elaboration)

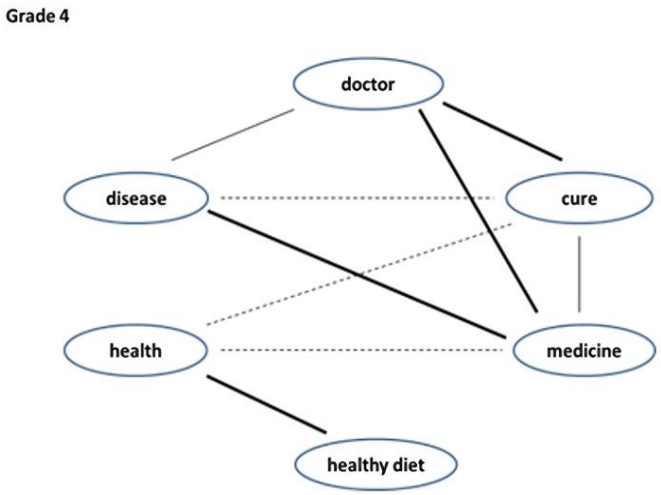

Figure 19. Conceptual networks between stimulus words in 'health' characteristic for the 4th graders (cut-off points: RC=0,20; 0.10; 0.05) (Source: Authors' own elaboration)

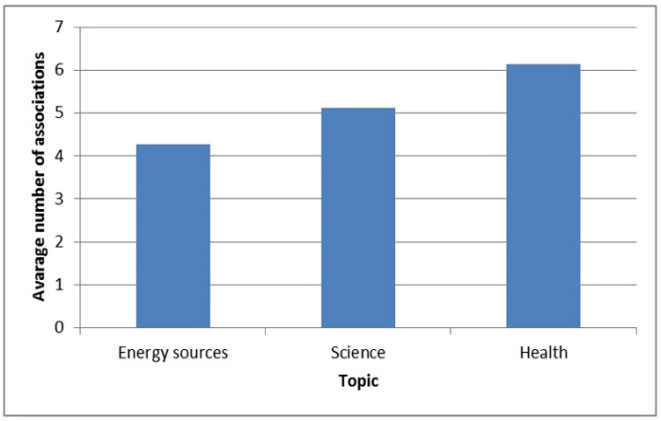

Figure 20. Average number of associations in different topics (Source: Authors' own elaboration)

Figure 19 shows conceptual networks between the stimulus words in the 'health' characteristic for the 4th graders (cut-off points: RC=0,20; 0.10; 0.05).

As can be seen in **Table 6**, there is a strong, significant correlation with the expert knowledge structure in the 'health' from grade 1 to grade 4 (except grade 2). This shows that already the cognitive structure of the 1st graders is very similar to that of experts.

DISCUSSION

Based on the average number of associations to the key concepts (**Figure 20**), the number of connections in the typical cognitive structures (**Figure 21**), and a strong correlation with expert cognitive structure (**Table 4**, **Table 5**, and **Table 6**) it can be concluded that the conceptual structure of the students studied is the most developed in the 'health' topic and the least developed in the 'energy sources' topic. This suggests that the cognitive structure of learners is fundamentally shaped by everyday experiences. However, the jump in the number of connections in the 'science' in the 3rd grade

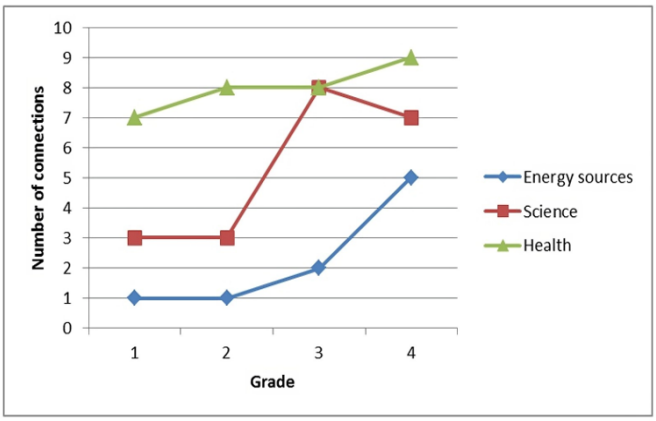

Figure 21. Number of connections in typical cognitive structures for different graders in different topics (Source: Authors' own elaboration)

and in the 'energy sources' in the 4th grade (**Figure 21**) is probably the result of schooling.

Based on the results presented above, we can conclude that the verbal version of the word association test is suitable for exploring the cognitive structure of young schoolchildren. Thus, our first hypothesis is confirmed. The number of associations and the strength of the links between the stimulus words tend to increase from the 1st to the 4th grade. This confirms our second hypothesis.

However, our hypothesis that there is a major change in cognitive structure in the 3rd grade when the Environmental science subject is introduced, could only be confirmed for the 'science' topic.

Our results clearly show that in topics, where learners have everyday experience ('health'), their cognitive structure is much more structured, with far fewer isolated elements than for topics with abstract concepts ('science' and 'energy sources'). This confirms our fourth hypothesis.

Our fifth hypothesis was only partially confirmed. Indeed, the typical cognitive structure of the 4th graders shows a strong significant correlation with that of experts. However, in the 'health' topic, where students have a lot of everyday experience, already knowledge structure of grade 1 students shows a strong significant correlation with the knowledge structure of experts.

CONCLUSIONS

Our results show that the verbal version of the word association test can be used to explore the cognitive structure of young students who are still uncertain about reading and writing. By means of word association tests, we have been able to demonstrate that the learners' cognitive structure is becoming more and more strongly related to concepts year by year. Our results clearly show that in topics, where learners have everyday experience, their cognitive structure is much more structured, with

far fewer isolated elements than for topics with abstract concepts.

Surprisingly, the typical cognitive structure of the 4th graders (and even the 1st graders in 'health') shows a strong, significant correlation with that of the experts. This is partly (in the case of 'science' and 'energy sources') a consequence of school education and partly a consequence of everyday experiences (mainly in the case of 'health').

Limitations are due to the fact that the sample is not representative and that we have not yet carried out a detailed statistical and content analysis of associations obtained. After a detailed statistical and content analysis of the associations, the research will also be carried out on complex topics such as sustainability, forest, aviation, and natural sciences. We are planning a comparative evaluation of the results of the word association test on the basis of background variables (e.g., gender, social circumstances, relationship to school, etc.). We are confident that our results will contribute to the development of science education for young pupils.

Funding: This study was supported by Hungarian Academy of Sciences (Research Programme for Public Education Development of the Hungarian Academy of Sciences, No. SZKF2022-11/2022).

Ethical statement: The author stated that the study is based on anonymized data from elementary school classes. Before conducting the study, the author obtained pertinent authorizations from the participants' schools and parents to develop and analyze the students' responses. Additionally, the teachers and students were informed about the study and participated voluntarily.

Declaration of interest: No conflict of interest is declared by the author.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the author.

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APPENDIX A

Table A1. Distribution of study sample

	Science	Energy source	Health	Total
Grade 1	29	30	30	89
Grade 2	34	32	34	100
Grade 3	34	34	35	103
Grade 4	34	32	32	98
Total	131	128	131	390

Table A2. Relationship strengths between stimulus words as determined by experts on a scale of zero to three

Science	Science	Experiment	Observation	Research	Explanation
Scientist	3.0	2.4	2.3	2.9	2.2
Science		2.4	2.1	2.9	2.3
Experiment			2.5	2.4	2.0
Observation				1.6	1.7
Research					2.2
Energy source	**Crude oil**	**Natural gas**	**Solar panel**	**Renewable energy source**	**Firewood**
Coal	2.3	2.2	1.1	0.8	1.1
Crude oil		2.6	0.6	0.6	1.4
Natural gas			0.6	0.9	1.3
Solar panel				2.8	0.8
Renewable energy source					1.5
Health	**Disease**	**Health**	**Medicine**	**Cure**	**Healthy diet**
Doctor	2.1	2.0	2.4	3.0	1.0
Disease		2.7	2.1	2.7	1.5
Health			1.5	1.5	2.4
Medicine				2.5	0.5
Cure					1.6

Table A3. Average number of associations in 'science' for different stimulus words

	Scientist	Science	Experiment	Observation	Research	Explanation
Grade 1	3.93	3.69	4.28	5.62	5.14	5.24
Grade 2	5.50	4.35	5.97	5.82	5.65	5.65
Grade 3	5.21	4.35	5.24	6.03	5.24	5.09
Grade 4	5.21	4.12	5.35	6.00	4.94	4.88

Table A4. Means of relatedness coefficients between stimulus words in 'science' for different grades

Grade 1	Science	Experiment	Observation	Research	Explanation
Scientist	0.11	0.07	0.01	0.03	0.01
Science		0.06	0.01	0.02	0.02
Experiment			0.02	0.02	0.01
Observation				0.01	0.04
Research					0.03
Grade 2	Science	Experiment	Observation	Research	Explanation
Scientist	0.20	0.11	0.02	0.04	0.01
Science		0.09	0.01	0.03	0.01
Experiment			0.02	0.02	0.01
Observation				0.03	0.03
Research					0.00
Grade 3	Science	Experiment	Observation	Research	Explanation
Scientist	0.16	0.11	0.05	0.06	0.03
Science		0.07	0.03	0.04	0.02
Experiment			0.06	0.05	0.02
Observation				0.07	0.02
Research					0.00
Grade 4	Science	Experiment	Observation	Research	Explanation
Scientist	0.20	0.09	0.01	0.06	0.00
Science		0.07	0.02	0.06	0.01
Experiment			0.01	0.04	0.00
Observation				0.05	0.01
Research					0.01

Table A5. Average number of associations in 'energy sources' for different stimulus words

	Coal	Crude oil	Natural gas	Solar panel	Renewable energy source	Firewood
Grade 1	3.67	2.20	3.17	4.40	2.80	4.73
Grade 2	5.09	3.12	4.03	5.69	3.03	5.75
Grade 3	4.50	3.09	3.36	5.24	3.68	5.56
Grade 4	5.38	3.62	3.25	6.50	4.09	6.28

Table A6. Means of relatedness coefficients between stimulus words in 'energy sources' for different grades

Grade 1	Crude oil	Natural gas	Solar panel	Renewable energy source	Firewood
Coal	0.02	0.01	0.02	0.00	0,09
Crude oil		0.01	0.00	0.00	0,01
Natural gas			0.02	0.01	0,02
Solar panel				0.03	0.02
Renewable energy source					0.00
Grade 2	Crude oil	Natural gas	Solar panel	Renewable energy source	Firewood
Coal	0.01	0.00	0.01	0.00	0.11
Crude oil		0.02	0.01	0.00	0.01
Natural gas			0.01	0.01	0.01
Solar panel				0.04	0.00
Renewable energy source					0.00
Grade 3	Crude oil	Natural gas	Solar panel	Renewable energy source	Firewood
Coal	0.02	0.01	0.00	0.01	0.10
Crude oil		0.01	0.00	0.01	0.01
Natural gas			0.01	0.02	0.02
Solar panel				0.06	0.01
Renewable energy source					0.01
Grade 4	Crude oil	Natural gas	Solar panel	Renewable energy source	Firewood
Coal	0.09	0.05	0.03	0.02	0.11
Crude oil		0.07	0.01	0.03	0.01
Natural gas			0.03	0.03	0.04
Solar panel				0.13	0.01
Renewable energy source					0.01

Table A7. Average number of associations in 'health' for different stimulus words

	Doctor	Disease	Health	Medicine	Cure	Healthy diet
Grade 1	5.47	4.83	4.83	4.10	4.70	5.10
Grade 2	7.03	6.09	5.97	6.03	4.91	6.82
Grade 3	6.31	6.31	5.89	6.26	6.00	7.82
Grade 4	7.53	8.25	7.16	6.59	5.47	7.19

Table A8. Means of relatedness coefficients between stimulus words in 'health' for different grades

Grade 1	Disease	Health	Medicine	Cure	Healthy diet
Doctor	0.13	0.01	0.21	0.22	0.01
Disease		0.02	0.18	0.07	0.02
Health			0.04	0.01	0.17
Medicine				0.16	0.04
Cure					0.02
Grade 2	Disease	Health	Medicine	Cure	Healthy diet
Doctor	0.08	0.02	0.14	0.25	0.01
Disease		0.04	0.18	0.04	0.02
Health			0.07	0.03	0.11
Medicine				0.16	0.05
Cure					0.02
Grade 3	Disease	Health	Medicine	Cure	Healthy diet
Doctor	0.15	0.03	0.18	0.34	0.02
Disease		0.05	0.18	0.10	0.02
Health			0.04	0.03	0.12
Medicine				0.14	0.03
Cure					0.02
Grade 4	Disease	Health	Medicine	Cure	Healthy diet
Doctor	0.15	0.02	0.20	0.26	0.00
Disease		0.04	0.21	0.08	0.00
Health			0.06	0.06	0.20
Medicine				0.19	0.02
Cure					0.03