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Developing and Evaluating Elementary-Level Teaching Materials "Magnetic Top": An Analysis of Questionnaire Using Text Mining

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Abstract The purpose of this study was to create and evaluate an educational magnetic top. The experiment was conducted with elementary school children at the Youngsters' Science Festival in Matsuyama, Japan. In order to evaluate the study, an open-ended questionnaire was created. Upon receiving permission from parents, 139 elementary school children were surveyed, which included 56 students from the lower grades, 54 students from the middle grades, and 29 students from the upper grades. The survey was analyzed using the text mining technique. As a result, three important results were gathered: 1) it became clear that most students in the middle grades stop feeling like they were bad at the screw tightening; and 2) Most students in the upper grades that had experience in motor learning, students tended to be able to adequately explain the principle of screw tightening; and 3) As long as students learn about the principles of motors, the teaching materials that are proposed in this study can be used to describe complex principles to students in all elementary school grade levels.

Keywords: *magnetic top, text mining, screw tightening, scientific principles*

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1. Introduction

Memorization is a powerful learning method in some sense that enables students to achieve high test scores. For example, "filled in from the right from the new moon, when it comes to the full moon also goes missing from the right. Born from the right, disappear from the right. Both remember in from the right." Thus became mood was found in phases of the moon. This was the puzzle, such as in front of the eye that deformed the scientific phenomena. To solve the puzzle, it was necessary to stimulate the intellectual curiosity of the learner. However, intellectual curiosity does not always leads to the understanding of science.

As a practical matter, memorization learning also yielded negative consequences; for example, students often forget what they have learned after completing a test. The fleeting nature of a sand castle is one analogy that emphasizes this finding. Yamaoka (2003) conducted a case study on students' interests in learning in which he studded a science class and assessed whether students asked questions to understand the underlying scientific principles [1]. There is a big difference in rote learning versus analytical learning, which is based on examining the principles of scientific phenomena when it comes to retaining information about scientific investigations. In order to recognize this difference in students, it is necessary to promote t intellectual curiosity in students, as this can lead to a more organic and enjoyable way of understanding complex ideas.

For better understanding natural phenomena, teaching materials that can be used to understand mysterious natural phenomena was developed. Therefore, this study focused on cognitive conflicts. According to Berlyne (Berlyne, trans 1966), cognitive conflict is explained by types such as suspicion, embarrassment, inconsistency, cognitive disharmony, confusion, inappropriate [2]. Furthermore, according to Novak (1998), when academic knowledge is integrated with everyday knowledge, a cognitive conflict occurs [3]. In this study, as a phenomenon different from everyday knowledge, focus on the "magnetic top". According to the Japanese course of study, learning about magnetization of the iron core and strength of the electromagnet is done in elementary school 5th grade. However, the "magnetic top" which is one of well-known toys is not treated in elementary school [4].

In Japan, events in which scientific experiments are conducted include hands-on classes and experimental workshops that are enjoyed by children and adults, and which have been implemented in a variety of places. One of these events is the Youngsters' Science Festival. In this study, I developed educational materials that were used at the Youngsters' Science Festival to accompany the observation of unfamiliar natural phenomena.

Yamaoka et al. (2016) drew attention to the elementary school students' difficulties in applying the practice of screw tightening as it relates to LED teaching material [5]. In this study, the screw tightening is important, too. Then, it was also focused on screw tightening in the production process.

2. Research Method

2.1. Investigation Timing and Object

From October 31 to November 1, 2015, the Youngsters' Science Festival was held in Ehime Prefecture, Japan [6]. In there, more than 50 groups did experimental workshops. Nearly three thousand people participated in the experimental workshops during the two days in which the Youngsters' Science Festival was held. The people who participated spanned a wide range of ages, from kindergarten to college students; however, the predominant age of participants were elementary school students.

Our group offered an experimental workshop about magnetic top in the festival. Among them, parental permission was obtained for 139 elementary school students and an open-ended questionnaire was conducted. Afterwards, the results of the questionnaire were analyzed. In this study, the elementary school students were separated into three groups: lower grades (1st and 2nd grade), middle grades (3th and 4th grade) and upper grades (5th and 6th grade). A breakdown of 139 elementary school students were surveyed, which included 56 students from the lower grades, 54 students from the middle grades, and 29 students from the upper grades.

2.2. Production of Magnetic Top

The largest group of participants in the Youngsters' Science Festival consisted of elementary school students. Therefore, the level of experimental workshops was often focused on elementary school students in the lower grades. In fact, on the day of the science celebration, an experimental commentary book was distributed to all participants, which was created with students from the lower elementary school grades in mind.

The development of teaching materials was accomplished with reference to the policy of Fujikawa et al. (2011), which focused on an experiment that contained the basic elements of the electrical circuit in order to develop increase student interest [7]. In accordance with this policy, a brief introduction on the process involved in creating a "magnetic top" is described below.

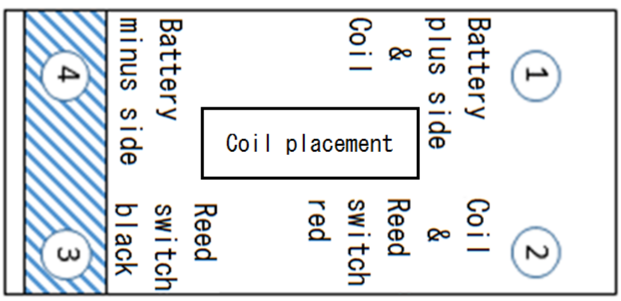

Figure 1. Component seal

The first step is to make a top with a donut-type ferrite magnet and a bamboo skewer. Subsequently, a base should be affixed to the coil with a pasting component seal as shown in Figure 1.

The hatched portion in Figure 1 was affixed to an aluminum tape. By using aluminum tape in the circuit, we expected that students would be more likely to relate electricity to the presence of the tape. For example, aluminum is a conductor, and electricity will not pass through the pasted aluminum tape. Thus, it becomes easy to trace an electric circuit with one's finger; therefore, such activities can be used as teaching materials for promoting the understanding of the electrical circuit for elementary school students.

However, since the targeted participants are students in the lower grades, it is determined that the soldering is difficult. Thus, the reed switch and the base of the LED, as seen in Figure 2, was prepared with pre-soldered.

Furthermore, because soldering is difficult, the connection of the conduction wire to the screw is possible, as is shown in Figure 3. Therefore, the pedestal that was used was a styrene board. Finally, the enameled wire, which extended 5cm beyond the screw at both ends, was wound in a certain direction to an iron bolt to form a coil. As is shown on the pedestal of Figure 1, the steps of the method are shown in ①, ②, ③, and ④ in Figure 3. Thus, it is clear that the conduction wire is connected with screws. In the above procedure, the completed model of the magnetic top was shown in Figure 4.

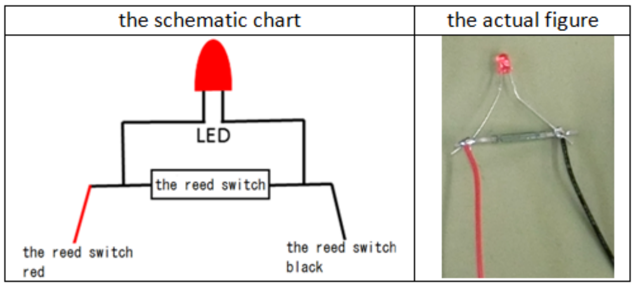

Figure 2. The reed switch and LED

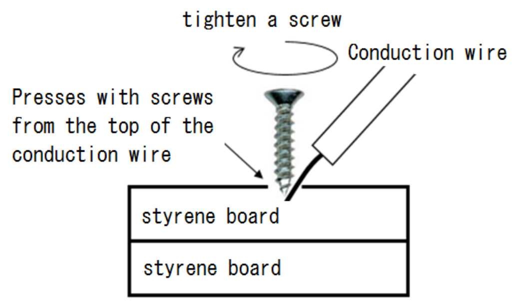

Figure 3. Connection of conduction wire by screws

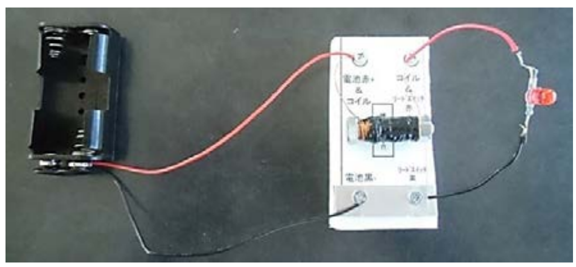

Figure 4. Completed model of the magnetic top

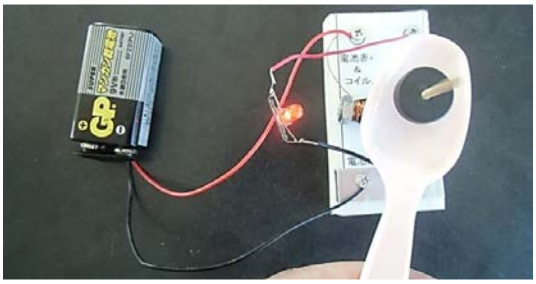

Figure 5. The condition in which the spinning top continues to circulate

The "magnetic top" in Figure 4 continues around the top, as shown in Figure 5. Thus, it is possible to observe a phenomenon that cannot be understood through simple observation. The teaching material "magnetic top" that are presented in this study remedies cognitive conflict with interactive activities.

2.3. Creating an Open-ended Questionnaire

For the 139 elementary school students from which parental permission was obtained, a questionnaire was conducted in which open-ended questionnaire were posed to the participants following the experimental workshops. Due to the fact that the subjects were elementary school students and that there was limited time during the Youngsters' Science Festival, a questionnaire was prepared ahead of time in which some questions were accompanied by possible answer choices. As a result, this questionnaire could be completed in a short amount of time on a single-sided A4-sized sheet of paper. Figure 6 shows the questionnaire.

As is shown in Figure 6, Question 1 assessed the students' basic attitudes about the level of difficulty regarding the insertion of the screw. Question 2 assessed, whether the participant was already familiar presented in the activity in order to evaluate whether or not special teaching materials could potentially remedy a cognitive conflict. Question 3 assessed whether it was possible to come up with a solution to the activity using teaching materials. Finally, Question 4 assessed whether the activity appropriately evaluated the scientific principles.

2.4. Questionnaire Analysis of Text Mining

To consider the results of the questionnaire, a database was created in which all the descriptions were translated into a text format. In order to evaluate elementary-level teaching materials "magnetic top", the text was analyzed using a text mining technique, after which the teaching materials were evaluated. This study was performed using the text analysis system KH Coder Ver.2. Beta.32 (hereafter, "KH Coder"), which was developed by Higuchi [8,9]. KH Coder uses a method of analyzing a variety of qualitative data, such as text, audio, and video data. This method incorporates aggressively specific methods of content analysis and can perform quantitative analysis of the data. By using KH Coder, the entire text can be divided into the smallest possible units; as a result, it is possible to extract more word patterns. In this study, using the KH Coder, a co-occurrence network was created which included all elementary grade levels, and consequently, an evaluation of the teaching materials was developed.

Grade______th

Q1. On the use of screw driver.
(1) Was it difficult for you to use the screw driver?
(2) How many times do you use screw driver a year?
(3) What activities do you often use screw driver?

Q2. What do you feel when using screw driver?

Q3. Challenges in using screw driver.
(1) When do you feel that using screw driver is difficult to use?
(2) How did you overcome the challenges in using screw driver?

Q4. What was the difference in using motor and magnetic top? Specify.

· Thank you for answering the questionnaire.

Figure 6. Questionnaire

3. Results and Discussion

3.1. The Results of the Questionnaire Using Text Mining

Using the KH Coder, an evaluation of word patterns was extracted from the free descriptions provided in the questionnaires. Table 1 summarizes the number of extracted words or word patterns that occurred in the answers to Question 1.

Table 1. The number of occurrences of extracting word in Question 1 (in part)

Question	Extracted word	Lower grades (n = 56)	Middle grades (n = 54)	Upper grades (n = 29)
Q 1 (1)	Difficult	35	20	10
	Easy	14	24	13
	A little difficult	2	6	1
Q 1 (2)	Not at all	20	15	3
	1 time or 2 times	13	11	8
	Within 10 times	16	16	1
	Over 10 times	7	12	17
Q 1 (3)	Home	26	26	12
	Exchange Battery	6	13	3
	Experimental workshops	1	3	6

The results of the chi square calculations are shown in Table 1 of Q1 (1), which accepts the null hypothesis as true (χ^2= 11.2, df = 4, p < .05). The results of the residual error analysis revealed that in the lower grades, there were many students who used the word "Difficult" in their answers, while among the participants of the middle grades, few used the word "difficult." Thus, it is clear that students' comprehension of the screw tightening mechanism improves in the middle and upper elementary grades.

The results of the chi square calculations as shown in Table 1 of Q1 (2) also accepts the null hypothesis as true (χ^2= 27.5, df = 6, p < .01). The results of the residual error analysis revealed that in the lower grade, there many responses included the phrase "Not at all," while in the upper grades, many responded with "Over 10 times." Thus, among students in the lower grades, it is clear that the there are few opportunities for students to experience or encounter the mechanism of screw tightening.

As is presented in Table 1 of Q1 (3), the null hypothesis is accepted as true (χ^2 = 27.5, df = 6, p < .01). The results of the residual error analysis revealed that in the lower grade, there were many "Not at all" responses, while in the upper grades, and there were many "Over 10 times" responses. Thus, in the lower grades, it is clear that the opportunity itself of screw tightens in everyday is small. Across all the grades, the opportunity for students to experience or encounter the mechanism of screw-tightening is usually presented in one's home, which usually occurs when a battery is exchanged; for example, when a toy's battery is replaced.

Table 2 summarizes the number of extracted words or word patterns that occurred in the answers to questions 2, 3, and 4.

From the result of question 2, it seemed that all grade children felt strange that the top would keep spinning around. However, it was a characteristic that students in the middle and upper grades asked why this natural phenomena took place.

In Question 3 (1), for all grades, the difficulty of coil making was observed. In addition, the solution of the problem, that is, in question 3(2), words such as "help me to the people" and "practice" were extracted. In Question 4 to explain the difference between the motor, it has been extracted the word "do not know" many in the low-grade and middle grade. This is, for children from the lower and middle grades, there were no motor of learning experiences and decomposed experience, it was evident that the question was a difficult one. In order to investigate the details of Question 4, it was summarized characteristic actual description in Table 3.

In Table 3, for example, a first-grade student provided his analysis of the top: "The idea of spinning was the reverse. I think that Motor is spinning the coil turns around?" His assessment demonstrates that it is possible to describe the process. Therefore, it does not mean that it is impossible to describe it to the lower grades.

Overall, among the children, there was motor learning and decomposition of the experience, and this let to them successfully associating production and the magnetic top.

Table 2. The number of occurrences of extracting word in Question 2, 3, and 4 (in part)

Question	Extracted word	Lower grades (n = 56)	Middle grades (n = 54)	Upper grades (n = 29)
Q2	Spin	37	32	16
	Top	21	25	12
	Electricity	5	5	0
	Lightning	3	7	1
	Why	0	5	4
Q3(1)	Coil	14	15	4
	Wind	10	9	6
	Spin	7	9	5
	Driver	5	3	1
	Top	1	6	7
Q3(2)	Practice	7	2	1
	Understand	6	1	0
	Effort	5	1	2
	Help	3	2	1
	Polite	0	3	1
	Think	0	3	3
Q4	Do not understand	21	13	2
	Spin	3	2	0
	Motor	2	2	1
	Nothing	0	0	2
	Magnet	0	3	0

Table 3. Characteristic actual description in Question 4 (In part)

Grade	Actual descriptive example
Lower grades	・The idea of spinning was the reverse. I think that Motor is spinning the coil turns around? (Grade 1) ・I was surprised with the turn so much to not connect with direct motor. (Grade 2)
Middle grades	・Motor is a compact. But, this is larger than motor, because it attached to various things. (Grade 3) ・The difference between spin the coil, and spin the magnet. (Grade 3) ・Motor and the top is the same mechanism. (Grade 4)
Upper grades	・Motor and the top is nearly the same. (Grade 5) ・Motor and the coma is the same mechanism. The number of conductive wire, the length, and sizes were different. (Grade 6)

3.2. Results of the Co-occurrence Network

Similar patterns of words appear in the questionnaire; in other words, the degree of co-occurrence among strong words was connected in a line to create a co-occurrence network. In the KH Coder, an optimal set includes a minimum number of occurrences in which one or more words were extracted. In addition, in the event in which a strong association of one word with another was detected automatically, this word grouping was also set in the sub-graph detection, which is indicated in the color-coded results.

The responses to Question 2 of the questionnaire are summarized in Figure 7, Figure 8, and Figure 9 to depict the co-occurrence network among the lower grades, middle grades, and upper grades.

In Figure 7, Figure 8, and Figure 9, across all grades, we can see that students were interested in both the spinning of the top and in the LED lighting. The lower grades tended to associate the word "trembling" with the word "turn." From this association, it is presumable that the top provoked hand trembling, which is a phenomenon that occurs when the battery's energy is used. In the middle grades and the upper grades, this characteristic is associated with higher-order thinking, as it provides an answer to the "why" question regarding why the top spins.

In Question 3(2) of the survey, in the lower grades, middle grades, and upper grades, the co-occurrence network is summarized in Figure 10, Figure 11, and Figure 12.

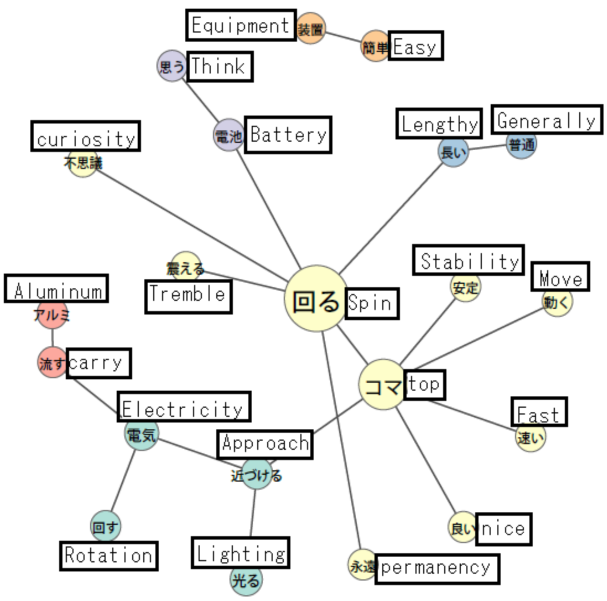

Figure 7. Question 2 of the co-occurrence network (Lower grades)

In Figure 10, Figure 11, and Figure 12, we have come up with a solution that overcomes the difficulty that has been discovered to vary with accordance to grade. For example, in the lower grades, the word such as "help", "other" and "person" was not associated with any other words or phrases. On the contrary, in the middle grades, phrases such as "tighten a screw" and "Spinning the top" were associated with the word "practice." Furthermore, in the upper grades, words such as "listen," "see," and "think" were extracted. Furthermore, the term for independent problem-solving, "performing concentrated," was also extracted. As described above, as the grade increased, students were more likely to resolve the conflict independently.

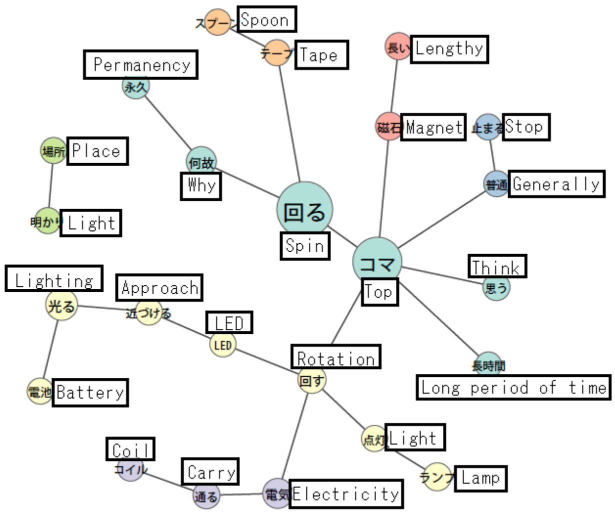

Figure 8. Question 2 of the co-occurrence network (Middle grades)

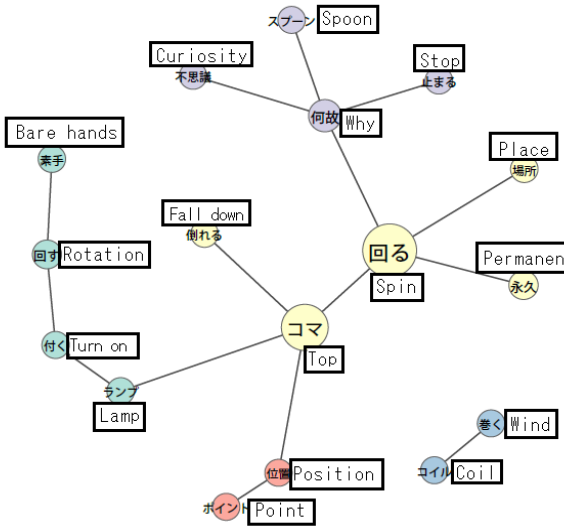

Figure 9. Question 2 of the co-occurrence network (Upper grades)

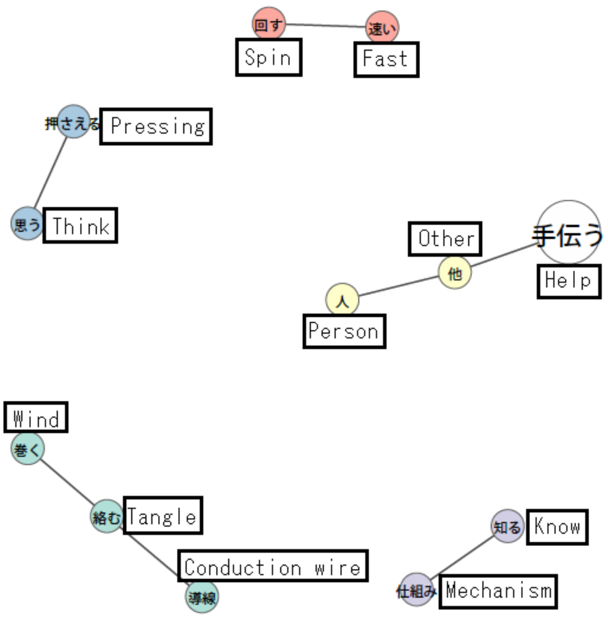

Figure 10. Question 3(2) of the co-occurrence network (Lower grades)

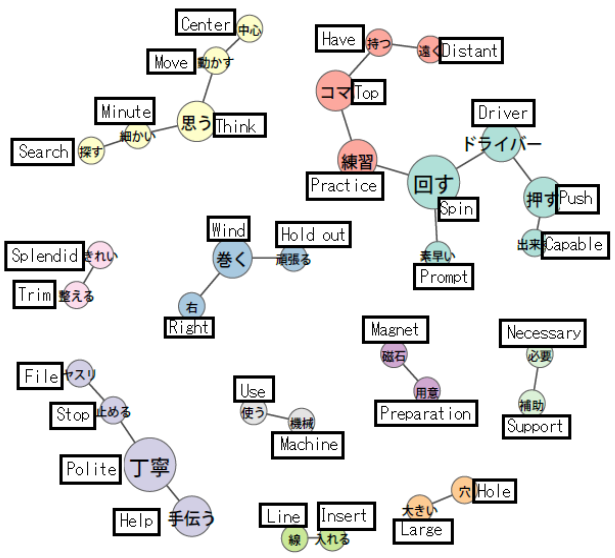

Figure 11. Question 3(2) of the co-occurrence network (Middle grades)

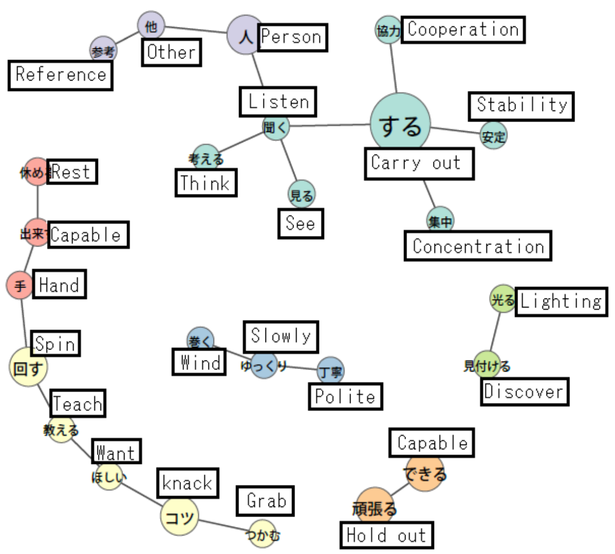

Figure 12. Question 3(2) of the co-occurrence network (Upper grades)

4. Conclusion

The awareness of the screw-tightening mechanism was apparent to students in all grade levels. With respect to the screw tightening mechanism, as students get older, their understanding of the scientific principles improved. In particular, it became clear that the understanding of the scientific principles correlated with those students who had more opportunities for learning about the screw tightening mechanism, such as battery replacement in toys. However, it was not until the students were in the later middle grades that they could actually perform the battery replacement of their toys on their own. From this point of view, the “magnetic top” was suitabe for students in the later middle grades.

Across all the grades, students tended to think that the scientific principle inherent to the “permanent motor-driven top” was strange. Specifically, students in the lower and middle grades tended to find it difficult to explain “why” the mechanism worked the way it did. However, lower grades were also able to describe what they found to be strange using expressions such as “the top was continuous spinning,” or “the LED was lighting.” In other words, the teaching material itself is considered to have been interesting to the broad range of students, even to those in the lower grades. Therefore, we argue that the teaching material proposed in this study promotes intellectual curiosity and leads to a greater understanding of the scientific principles undergirding natural phenomena.

In addition, the question about the difference between the motor and the “permanent motor-driven top” generated many word expressions in which students lower and middle grade students claimed they “do (did) not know.” However, as is evident in the opinion “The idea of spinning was the reverse. I think that Motor is spinning the coil around? (1st grade)”, children with motor-learning experience were able to associate the motor with the magnetic top. Therefore, in the upper grades, for the students who learned about the motor, the teaching materials proposed in this study were considered to be effective and to accelerate the understanding of science content. At the same time, even in the lower grades, by performing the contrivance such as learning a set of motors; therefore, the teaching material was considered to be effective.

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