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Study on Sixth Grade Elementary School Pupils' Scientific Concept Formation of Metals

Yukinori UTSUMI[*1]

This study explores 6th grade elementary school pupils' conceptions and understandings of properties of metals in Japan. To facilitate this research, 101 pupils in 6th grade participated in a questionnaire survey. The survey revealed four main points: First, 41.6% of the participants recognized that metals have electrical conductivity. Second, very few of them recognized that metals have metallic luster and heat conductivity. Third, none of them recognized that metals are malleable and ductile. Finally, a certain number of them recognized the properties of iron as the ones of metals, because iron is the most familiar metal in their daily lives. The results of this study indicate that 6th grade pupils in Japan have piecemeal understanding of the properties of metals. Therefore, this work of research concludes that the contents and the order of the properties of metals should be reconsidered from the perspective of "learning progressions" so as to enhance their conceptions and understandings of properties of metals.

Key words: 6th grade elementary school pupil, recognition of concept of metal, properties of metal, questionnaire survey

1. Introduction

The concept of matter is considered to be a fundamental concept for achieving scientific literacy, while students developing an understanding of its particulate nature is one of the main targets of chemistry curricula (Tsapali, Quinn, Ellefson, Schlottmann and Taber, 2018). Pupils hold many incorrect ideas about science topics which are on the elementary school curriculum and these ideas are of considerable importance in the learning process, as they are the foundations upon which new knowledge is built (Pine, Messer and John, 2001).

Shiba, Yamasaki, Nakata and Ogawa (2011) indicate that pupils in elementary schools in Japan have piecemeal understanding of properties of metals and therefore, it is difficult to develop their conceptions and understandings of properties of metals. For example, according to the result of a research on the scholastic standards test (Tokyo Syoseki, 2017), the rate of right answers (the answer to why aluminum cans and steel cans can be separated by using a magnet) was 42.6%. This indicates that almost half the pupils do not understand that steel is a magnetic substance, and aluminum is non-magnetic substance.

Properties of metals are taught in both chemistry and physics in elementary school science in Japan. Thus, systematic learning cannot be implemented well. Therefore, it is likely that they understand properties of metals fractionally, although metals are familiar materials.

*1 Faculty of Education, Gifu University

This study aims to examine 6th grade elementary school pupils' conceptions and understandings of properties of metals in Japan by conducting a questionnaire survey.

2. Properties of metals in elementary school science textbooks in Japan

Table 1 shows properties of metals which are mentioned in elementary school science textbooks (Mouri, et al., 2014) in Japan. These properties of metals strictly reflect the ministry's curriculum guideline (Ministry of Education, Culture, Sports, Science and Technology, 2008). In elementary school science textbooks in Japan, metallic luster, malleability and ductility are not categorized as properties of metals and electric conductivity and heat conductivity are identified. Properties of metals are covered in two fields: physics and chemistry.

Table 1 Properties of metals in elementary school science textbooks in Japan (Mouri , et al. , 2014)

Grade	Field	Unit	Properties of metals	Scientific concept
3rd	Physics	Path of electricity	・ Metals conduct electricity well.	Electric conductivity
		Properties of metals	・A magnet attracts objects are made of iron. ・Magnets do not attract any metal except iron. ・When iron comes in contact with magets, it becomes magnetic.	Magnet
	Chemistry	Weigh and volume	・Even if substances are of the same volume, their weights differ.	Weigh, Volume
4th	Chemistry	Metal, water, air and temperature	・ When metals get warm, their volume increases. When they cool, their volume reduces. ・Metals get warm in the particular area where they are heated, and the other parts warm over time.	Heat conductivity
5th	Physics	Functions of electricity	・When an iron core is put into coil and is electrified, it becomes a magnetic iron core that attracts iron.	Electric magnet
6th	Physics	Use of electricity	・When a heating wire is electrified, it produces heat.	Heating wire
	Chemistry	Properties of water solution	・ Dilute hydrochloric acid melts metals. ・ Hydrochloric acid changes some metals into other substances.	Chemical reaction, Acid

Note: The shaded region shows two properties of metals: electric conductivity and heat conductivity.

3. Method

In order to examine 6th grade elementary school pupils' conceptions and understandings of properties of metals in Japan, a questionnaire survey was conducted for them and their responses were analyzed. Table 2 shows objects used for their questionnaire survey. The pupils are familiar with these objects in daily life.

This study was conducted for a total of 103 6th grade pupils in September, 2018, in the middle of 6th grade. Completed questionnaires of 101 pupils were analyzed (N=101, percentage of 101 pupils). The questionnaires presented pictures of objects. They also had three questions, Q1-Q3, which the pupils were required to answer with a "yes" or a "no" The questionnaires also had Q4, which allowed participants

to give descriptions. The participants' answers were classified into 13 categories.

Table 2 Objects used for pupils' questionnaire survey

No.	Object	Material	No.	Object	Material
1	Aluminum foil	Aluminum	10	1-yen coin	Aluminum
2	Notebook	Paper	11	10-yen coin	Bronze (Cu:95%, Zn:4~3%, Sn:1~2%)
3	Rubber band	Rubber	12	100-yen coin	Cupronickel (Cu:75%, Ni:25%)
4	Chopsticks	Wooden	13	Glass	Glass
5	Pencil lead	Black lead, clay	14	Paper cup	Paper
6	Ruler A	Bamboo	15	Point protector	Plastic
7	Ruler B	Plastic	16	Stapler needles	Steel (with adhesive)
8	Coffee can	Steel (painted)	17	Thumbtack	Steel (with plating)
9	Juice can	Aluminum (painted)	18	Clip	Steel

Q1. Does the object in the picture conduct electricity?
Q2. Do magnets attract the object in the picture?
Q3. Is the object in the picture a metal?
Q4. What is a metal like?

4. Result

4.1. The recognition of objects with electric conductivity

Table 3 shows the pupils' responses to Q1: Does the object conduct electricity?

Table 3 Pupils' responses to Q1: Does the object conduct electricity? (*N*=101)

No.	Object	Electrical conductivity	Number (%)		No.	Object	Electrical conductivity	Number (%)	
			Yes	No				Yes	No
1	Aluminum foil	✓	90(89.1)	11(10.9)	10	1-yen coin	✓	57(56.4)	44(43.6)
2	Notebook		3(3.0)	98(97.0)	11	10-yen coin	✓	77(76.2)	24(23.8)
3	Rubber band		3(3.0)	98(97.0)	12	100-yen coin	✓	72(71.3)	29(28.7)
4	Chopsticks		8(7.9)	93(92.1)	13	Glass		8(7.9)	93(92.1)
5	Pencil lead	✓	50(49.5)	51(50.5)	14	Paper cup		4(4.0)	97(96.0)
6	Ruler A		9(8.9)	92(91.1)	15	Point protector		4(4.0)	97(96.0)
7	Ruler B		5(5.0)	96(95.0)	16	Stapler needles	(✓)	95(94.1)	6(5.9)
8	Coffee can	(✓)	71(70.3)	30(29.7)	17	Thumbtack	✓	92(91.1)	9(8.9)
9	Juice can	(✓)	78(77.2)	23(22.8)	18	Clip	✓	75(74.3)	26(25.7)

Note:1) The shaded region shows the right answers.
2) The mark (✓) indicates that the object is made from metal but that it is not a good conductor of electricity.

The right answers on objects which had electric conductivity were 90 pupils (89.1%) on aluminum foil, 50 pupils (49.5%) on pencil lead, 57 pupils (56.4%) on 1-yen coin, 77 pupils (76.2%) on 10-yen coin, 72 pupils (71.3%) on 100-yen coin, 92 pupils (91.1%) on thumbtack and 75 pupils (74.3%) on clip. Many pupils recognized electric conductivity of aluminum foil and thumbtack. However, fewer pupils recognized electric conductivity of 1-yen coin than them. Objects with electric conductivity which is found in school textbooks is aluminum foil, 1-yen coin, 10-yen coin, coffee can and juice can. It says something to the effect that the surface of cans need to be filed on the surface by abrasive paper to conduct electricity well.

The picture of cans in a questionnaire is that the surface of cans is not filed on the surface. The answers that cans had electric conductivity was 71 pupils (70.3%) on coffee can (Figure 1) and 78 pupils

(77.2%) on juice can (Figure 2). These pupils didn't recognize that cans didn't conduct electricity, because of the painted surface, although metals had it. The same is true of stapler needles which didn't it because of the surface with adhesive and coating, although stapler needles was iron and had it. It is considered that they could think that these objects were metals by appearance. Pencil lead is not found in school textbooks. Therefore, it is likely that pupils judged it from their experience in daily life.

On the other hand, the right answers on objects which had electrical insulation were 98 pupils (97.0%) on notebook and on rubber band, 93 pupils (92.1%) on chopsticks and glass, 92 pupils (91.1%) on Ruler A, 96 pupils (95.0%) on Ruler B, 97 pupils (96.0%) on paper cup and point protector. It showed that only a few pupils recognized objects which had electrical insulation.

Figure 1. Coffee can
Note: labeled as steel.

Figure 2. Juice can
Note: labeled as aluminum.

4.2. The recognition of objects with magnetic substance

Table 4 shows the pupils' responses to Q2: Do magnets attract the object?

Table 4 Pupils' responses to Q2: Do magnets attract the object? (*N*=101)

No.	Object	magnetic substance	Number (%)		No.	Object	magnetic substance	Number (%)	
			Yes	No				Yes	No
1	Aluminum foil		23(22.8)	78(77.2)	10	1-yen coin		22(21.8)	79(78.2)
2	Notebook		0(0)	101(100)	11	10-yen coin		47(46.5)	54(53.5)
3	Rubber band		0(0)	101(100)	12	100-yen coin		57(56.4)	44(43.6)
4	Chopsticks		0(0)	101(100)	13	Glass		2(2.0)	99(98.0)
5	Pencil lead		24(23.8)	77(76.2)	14	Paper cup		0(0)	101(100)
6	Ruler A		0(0)	101(100)	15	Point protector		2(2.0)	99(98.8)
7	Ruler B		2(2.0)	99(98.0)	16	Stapler needles	✓	93(92.1)	8(7.9)
8	Coffee can	✓	79(78.2)	22(21.8)	17	Thumbtack	✓	89(88.1)	12(11.3)
9	Juice can		55(54.5)	46(45.5)	18	Clip	✓	87(86.1)	14(13.9)

Note: The shaded region shows the right answers.

The number and proportion of right answers on objects which had a magnetic substance were as follows: 79 pupils (78.2%) on coffee can, 93 pupils (92.1%) on stapler needles, 89 pupils (88.1%) on thumbtack and 87 pupils (86.1%) on clips. Therefore, the rate of pupils who recognized magnetic substance of these objects was high. The number and proportion of wrong answers on the objects which had magnetic substance were as follows: 23 pupils (22.8%) on aluminum foil, 24 pupils (23.8%) on pencil lead, 55 pupils (54.5%) on juice can, 22 pupils (21.8%) on 1-yen coin, 47 pupils (46.5%) on 10-yen coin, 57 pupils (56.4%) on 100-yen coin. It is considered that these pupils thought that these objects had

magnetic substance because of their electrical conductivity. The fact that these pupils failed to recognize metals with a magnetic substance is also attributed to the fact that they had only interacted with iron in prior learning.

Contrastingly, the number and proportion of right answers on objects which did not have magnetic substance were as follows: all pupils (100%) on notebook, rubber band, chopsticks, ruler A and paper cup, and 99 pupils (98.0%) on ruler B, glass and point protector. Therefore, the rate of pupils who recognized that these objects did not have a magnetic substance extremely high.

4.3. The recognition of objects of metals

Table 5 shows the pupils' responses to Q3: Is the object a metal?

Table 5. Pupils' responses to Q3: Is the object a metal? (*N*=101)

No.	Object	Metal	Number (%)		No.	Object	Metal	Number (%)	
			Yes	No				Yes	No
1	Aluminum foil	✓	43(42.6)	58(57.4)	10	1-yen coin	✓	45(44.6)	56(55.4)
2	Notebook		0(0)	101(100)	11	10-yen coin	✓	61(60.4)	40(39.6)
3	Rubber band		0(0)	101(100)	12	100-yen coin	✓	75(74.3)	26(25.7)
4	Chopsticks		0(0)	101(100)	13	Glass		6(5.9)	95(94.1)
5	Pencil lead		12(11.9)	89(86.1)	14	Paper cup		0(0)	101(100)
6	Ruler A		1(1.0)	100(99.0)	15	Point protector		3(3.0)	98(97.0)
7	Ruler B		4(4.0)	97(96.0)	16	Stapler needles	✓	88(87.1)	13(12.9)
8	Coffee can	✓	70(69.3)	31(30.7)	17	Thumbtack	✓	94(93.1)	7(6.9)
9	Juice can	✓	65(64.4)	36(35.6)	18	Clip	✓	78(77.2)	23(22.8)

Note: The shaded region shows the right answers.

The number and proportion of right answers on objects made from metals were as follows: 43 pupils (42.9%) on aluminum foil, 70 pupils (69.3%) on coffee can, 45 pupils (44.6%) on 1-yen coin, 61 pupils (60.4%) on 10-yen coin, 75 pupils (74.3%) on 100-yen coin, 88 pupils (87.1%) on stapler needles, 94 pupils (93.1%) on thumbtack and 78 pupils (77.2%) on clip. The rate of right answers on objects which were judged based on metallic luster seen in the picture was relatively high. However, the rate of right answers on coffee can and juice can (painted on the surface), 1-yen coin, 10-yen coin and 100-yen coin, in which metallic luster was not seen was lower than that on the point protector, stapler needles and thumbtack in which metallic luster was seen. The rates of right answers on aluminum foil and 1-yen coin were in the same range and lower level of recognition of these objects was relatively lower than other objects. 12 pupils (11.9%) answered that pencil lead which was not a metal was a metal. It is considered that they could have a misconception, because it has electric conductivity.

The number and proportion of right answers on objects which is made from non-metals were extremely high: all pupils (100%) on notebook, rubber band, chopsticks and paper cup, and 100 pupils (99.0%) on ruler A and on ruler B, 95 pupils (94.1%) on glass and 98 pupils (97.0%) on point protector.

4.4. The recognition of properties of metals

Table 6 shows the pupils' responses to Q4: What is a metal like?

Table 6. Pupils' responses to Q4: what is a metal like? (*N*=101)

Properties etc.	Number (%)	Properties etc.	Number (%)
Metallic luster	5(5.0)	Magnetic property	47(46.5)
Electric conductivity	42(41.6)	Hardness	14(13.9)
Heat conductivity	1(1.0)	Iron	9(8.9)
Malleability	0(0)	Kinds of metals	8(7.9)
Ductility	0(0)	Color of appearance	6(5.9)
		Kind of Mineral	6(5.9)
		Get rusted	3(3.0)
		Other	11(10.9)

Note: The shaded region shows properties which metals have.

Pupils in Japan learn electric conductivity in 3rd grade and learn heat conductivity as properties of metals. However, only 42 pupils (41.6%) recognized electric conductivity. Therefore, the rate of it was difficult to determine. Only one pupil (1.0%) recognized heat conductivity. Therefore, the rate of it was very low. None of pupils (0%) recognized malleability and ductility.

Contrastingly, 47 pupils (46.5%) recognized magnetic property of metals. It seems likely that they would have a misconception that metals have magnetic properties based on their prior learning experience that iron has magnetic properties.

14 pupils (13.9%) recognized hardness, 9 pupils (8.9%) recognized iron, 8 pupils (7.9%) recognized different kinds of metals such as iron, aluminum, copper, etc., 6 pupils (5.9%) recognized color such as silver and copperish, 6 pupils (5.9%) recognized different kinds of minerals, and 3 pupils (3.0%) recognized rusting. It seems they judged metals by their perception of them in their daily life and their pre-existing knowledge.

5. Discussion

This study was conducted to explore 6th grade elementary school pupils' conceptions and understandings of properties of metals in Japan. It can be gathered from the results that they fractionally understand properties of metals (metallic luster, electric conductivity, heat conductivity, malleability, and ductility), though metals are familiar materials. They learn electric conductivity in 3rd grade and cover heat conductivity as one of the properties of metals. Therefore, the number of pupils who recognize electric conductivity accurately was high between the lower 70% and lower 90% range except for 1-yen coin, judging from Table 3.

However, the number of pupils who recognized that coffee can and, juice can were painted on the surface and stapler needles with adhesive had electric conductivity was high between the lower 70% and lower 90% range. Teachers should teach electric conductivity accurately on the basis that pupils are likely to have a misconception about objects such as coffee cans, juice cans and stapler needles.

With regard to magnetic property, the number of pupils who recognized that objects which had electric conductivity also had magnetic properties was moderate, judging from the rate of pupils who recognized that aluminum foil, juice can, 1-yen coin, 10-yen coin and 100-yen coin had magnetic properties.

The rate of right answers on objects made from metals ranged between the lower 40% and lower 90% range, making a difference among objects. The rate of right answers in this category was relatively high, because pupils could judge stapler needles, thumbtack and clip from the metallic luster seen in pictures. They do not learn that metals have metallic luster in elementary school science. Nevertheless, they could recognize that on the basis of their daily life experiences, whereas the rate of right answers on objects made from non-metals was quite high between the lower 90% and 100% range.

41.6% of pupils recognized that metals had electric conductivity. Few of them recognized electric conductivity and heat conductivity of metals. However, none of them recognized malleability and ductility of metals. When they judge properties of objects as to whether they are a metal or a non-metal from appearance, they are likely to judge them on the basis of their experience in daily life. This is true based on the fact that they judge objects depending on their match with the mental image, 3rd grade pupils in Japan learn that iron, aluminum, etc. are metals and metals conduct electricity well. Pupils in 4th grade learn that metals get warm depending on where they are heated, and therefore, the whole chunk of metal warms over time. In elementary school science in Japan, properties of metal, metallic luster, electric conductivity, heat conductivity, malleability and ductility are not taught comprehensively. Therefore, it is considered that it is difficult for pupils to develop their conceptions and understandings of properties of metals. It is suggested that a metal is regarded as material distinguishable from other materials and this encourages pupils to recognize metals on the basis of their properties as is the case in England (Department for Education, 2013).

6. Conclusion

41.6% of pupils recognized that metals had electric conductivity as one of the properties of metals, while every few recognized metallic luster and heat conductivity. None of them recognized their malleability and ductility. When they judge whether an object is a metal, it is likely that they would judge properties of metals from ones of iron, which is the most familiar metal in daily life. In other words, they have piecemeal understanding of properties of metals, although metals are familiar materials.

Iron and aluminum are taught in elementary school science in Japan. However, copper, nickel and cobalt are not. They could develop their conceptions and understandings of properties of metals appropriately, by learning about the properties of metals by comparing the properties of daily materials and the understanding of common properties. In addition, it is suggested that the contents and the order of properties of metals should be reconsidered from a perspective of "learning progressions" to develop their conceptions and understandings of properties of metals.

7. Limitations of the study

There are two limitations this study faced. One limitation is that "yes" or "no" questions were not the most suitable means to elicit pupils' understandings about properties of metals, because they force pupils to answer questions about some properties of metals they may not understand by a simple "yes" or "no", and because pupils' thinking is often more complex than a simple "yes" or "no". Another limitation is that the open question Q4 might introduce a bias to answering questions, for it was pointed out to the pupils in the questions Q1-Q3 that conductivity and magnetic properties are categories which they could consider when thinking about metals, whereas malleability and ductility were not parts of any former questions.

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Additional notes

This study has been significantly revised by adding new analysis based on the data presented at

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