Automated Evaluation of Students Comments Regarding Correct Concepts and Misconceptions of Convex Lenses

Masaru Taga
Faculty of Agriculture
Ryukoku University
Otsu, Japan
taga@agr.ryukoku.ac.jp

Toshihiro Onishi
Faculty of Science and Technology
Ryukoku University
Otsu, Japan
t-onishi@rins.ryukoku.ac.jp

Sachio Hirokawa
Research Institute for Information Technology
Kyushu University
Fukuoka, Japan
hirokawa@cc.kyushu-u.ac.jp

Abstract— **It is important for teachers to understand whether students have learned correct concepts or misconceptions. To identify correct concepts and misconceptions, we attempted to analyze the characteristics of students' concept descriptions using machine learning. It has been mentioned that university students retain the misconception that "light refracts at the center line of a convex lens" due to the influence of the learning construction method in junior high school. Therefore, the descriptions from 104 Japanese university third-graders (36 from the faculty of social studies and 68 from the faculty of science and engineering) were analyzed by text mining using a support vector machine, and their feature words were identified. As a result, it was possible to classify the characteristics of the descriptions as a correct concept or misconception based on the feature words.**

Keywords-support vector machine; misconception; convex lens; junior high school; teaching method

I. INTRODUCTION

In science classes, students gradually acquire scientific concepts as per their age. Additionally, there are naive concepts learned naturally during childhood, which are often scientifically incorrect. It is the role of science education to correct such misconceptions and to promote correct scientific concepts. However, there are cases in which students acquire misconceptions from science classes. If teachers could easily become familiar with these correct concepts and misconceptions, teaching methods could be effectively improved. We attempted to analyze the features of students' descriptions—both of correct concepts and misconceptions—using machine learning. In this analysis, the concept of a convex lens was used as an example.

Japanese students learn about the convex lens in science class during the first year of junior high. They study the change in the distance between the lens and object, and the relationship between the distance and images—real and virtual. In these classes, the drawing method is used by which the optical path is shown to be refracted at the longitudinal center line of the convex lens. Taga and Onishi [7] found that many university students had significantly misconceived that parallel incident light bends at the center of a convex lens—a misconception resulting from the influence of the drawing method.

It is important for teachers to hold classes that change misconceptions into correct concepts, or do not initially result in misconceptions. As such, it is important for teachers to be able to identify whether students have learned correct concepts or misconceptions. To facilitate this, the survey results featuring concept descriptions from the 104 students in [7] were analyzed by machine learning, and their feature words were revealed. We used the machine learning method of SVM and feature selection in [1] and [5] to extract characteristic words from the comments of students.

In this study, we examined the description from each student considering both the correct concept (twice refraction at the surface of the convex lens) and the misconception (one refraction at the center of the convex lens), as in [7]. As an analysis, we applied an SVM and attribute selection to a positive example of a sentence from a student who selected the mistake, and to other negative examples. As a result, we observed the highest discrimination performance with an F value of 0.8448 and accuracy of 0.7809 for 16 feature words–8 positives and 8 negatives. In addition, we analyzed feature words such as, "understand" used by students with correct concepts, and "learn" used by students with misconceptions.

The course of optics and photonics is taken up by UNESCO, and active learning teaching materials have been developed in [6]. Subsequently, there have been extensive research and numerous reports on the subject using this material as in [2], [3], and [8]. However, as far as the authors know, the present paper is the first trial to investigate students' misconceptions based on their free-style text using a text mining method.

II. DESCRIPTION OF SCIENCE TEXT BOOKS OF JUNIOR HIGH SCHOOL

A. *Description of Refraction*

In junior high science classes, first graders learn about rectilinear propagation, reflection (the incident angle, the reflection angle, and the law of reflection), refraction (the refraction angle), and the nature of the convex lens (the real and virtual image). About reflection and refraction, the Japanese teaching guideline says, “Experiments on reflection and refraction of light are performed, and it could be found the regularity that light is reflected and refracted at the boundary surface of materials such as water and glass” in [4]. When Japanese text books introduce refraction experiments, there are descriptions of refraction and the refraction angle occurring at the boundary of different substances, such as water and glass.

B. *Description of Convex Lens Drawing Method*

Five different Japanese science textbooks describe focus, focal length, real image, and virtual image as “function of convex lens.” In addition, they explain a real image to be when the object is outside the focal point of the convex lens, and a virtual image to be when the object is inside the focal point by the drawing method. Figure 1(A) is a drawing of a real image, and Figure 1(B) is that of a virtual image. In this method, the light refracts at the center line (broken line) of the lens. Each of the textbooks describe these diagrams, as in [7]. Additionally, science teachers draw the same diagrams on the board for students when teaching about real and virtual images.

（A）　　　　　　　　（B）

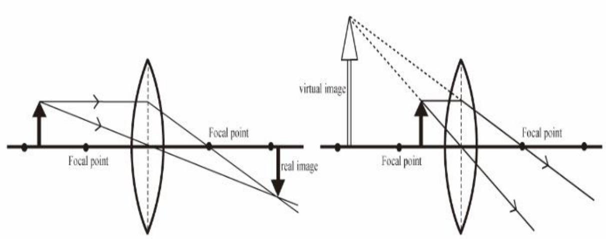

Figure 1. Drawing method for real and virtual images used in science textbooks of junior high school in Japan, as in [7].

C. *Experiment Procedure*

Figure 2 shows selections of the naive concept survey conducted by Japanese university students, as in [7]. They chose a figure from ① to ⑤ which shows the relationship between light rays and a convex lens. In addition, the students wrote the reasons for their choice. The drawing that depicts the correct concept is ③, and the misconception is represented by ②. Subsequently, we analyzed the student responses by using machine learning to gain a familiarity with the characteristics of the correct concepts and those of the misconceptions.

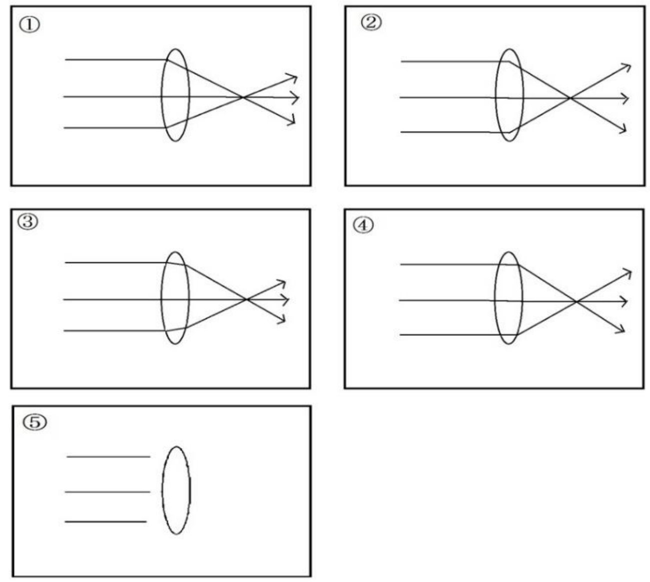

Figure 2. Selection of naive concept survey conducted by university students as in [7].

III. TEXT MINING OF COMMENTS

104 Japanese university students were asked to select one of five diagrams of a normal and virtual image generated by a convex lens. Furthermore, we asked them to describe the reason for their choice in free-style text. We applied text mining—as in [1] and [5]—to their descriptions and extracted feature words to distinguish between the students who made the correct choice, and those who made the incorrect choice. We used SVM-light-perf as a machine learning tool. The data analyzed in [7] was used.

We conducted the following two experiments. In the first, the sentences from the 33 students who chose the correct answer, ③, were used as positive data, while the sentences from the remaining 71 students were used as negative data. Subsequently, we extracted the characteristic words from all examples. In the second experiment, the sentences from the 62 students who chose the incorrect answer, ②, were taken as positive examples, while the remaining sentences were taken as negative examples. Again, the characteristic words were extracted from all examples.

TABLE I. RESPONSE OF STUDENTS

Diagram	①	②	③	④	⑤	total
Students	5	62	33	3	1	104

In the first step of each experiment, we vectorized the sentence of each student using all of the words and generated a model that distinguishes between positive and negative examples using SVM-light-perf. The model is represented as a vector of the weight *weight(w_i)* of each word, w_i, together with a constant, *b*. The weight of a word shows the distance of the word in the vector space from the hyperplane that separates the positive and negative data. If the weight is positive, the word is considered to be characteristic of positive data. If the weight is negative, the word is considered to be characteristic of negative data. The predicted weight, *guess(sk)*, of the sentence of a student, s_k, is calculated with the vector

$$guess(s_k) = b + \sum_{i=1}^{i=m} weight(w_i) * \delta(s_k, w_i),$$

where $\delta(s_k, w_i)$ is 1 if the word w_i occurs in the sentence of the student s_k, 0 times otherwise.

In the second step of the experiment, we used the top *N* positive words and bottom *N* negative words, with respect to the $weight(w_i)$, for the vectorization of sentences and evaluated the prediction performance. All of the comments are very short sentences averaging 23 words in length. The number of distinct words is 162. There are 88 words that appear in only one comment. We excluded those 88 words as candidates for characteristic words. Thus, we used the 74 words that were used by more than two students in our experiment. We iterated this process varying *N = 1, 2, ..., 10, 20, 30, 40,* and *50*, in order to find the *N* that maximizes discrimination performance. Incidentally, in addition to searching for parameter *N*, the search was conducted in the range of the SVM misclassification parameter *C*, from 1 to 100.

A. Analysis of Comments from Students who Chose Answer ②

Figure 3 shows the discrimination performance when the SVM is applied with the sentences from the students who chose the incorrect answer, ②, used as positive samples; and the other sentences as negative samples. The x-axis represents the number of words, N, for vectorization. We used *C*=20 for the SVM *C* parameter. Both F-measure and accuracy exhibit the highest scores in the range of *N*=4 to *N*=30.

When *N*=8, the best prediction performance is observed. This means that the comments belonging to students who made an incorrect selection can be identified with 8 positive and 8 negative words, for a total of 16.

Table II shows the top 10 positive and negative feature words of the students who chose the wrong answer, ②. If the weight of a word is positive, it is a characteristic word of those students. If the weight is negative, it is a characteristic word of the other students.

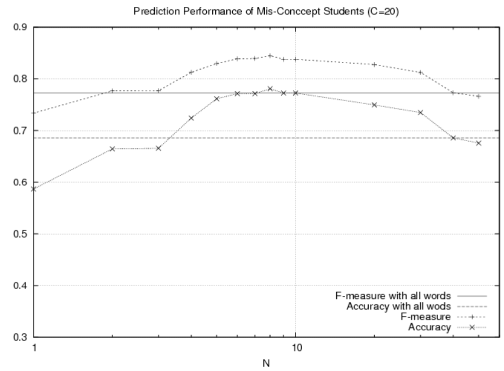

Figure 3. Prediction performance of misconcept student.

TABLE II. POSITIVE AND NEGATIVE FEATURE WORDS (MISCONCEPTION)

	POSITIVE FEATURE WORDS			NEGATIVE FEATURE WORDS		
k	weight(w)	df(w)	word	weight(w)	df(w)	word
1	2.5555	11	center	−2.6224	2	near
2	2.2643	3	where	−2.0892	7	happen
3	2.2148	5	axis	−1.5884	3	science
4	1.9329	13	“yo-u”	−1.4480	11	when
5	1.8981	15	learn	−1.4339	2	parallel
6	1.8132	2	textbook	−1.3988	2	done
7	1.4691	10	for	−1.3028	2	reflection
8	1.4044	13	middle	−1.2946	3	understand
9	1.2251	2	air	−1.2768	2	do
10	1.1532	5	focus	−1.1846	9	air

B. Analysis of Comments of Students who Chose Answer ③

Figure 4 shows the discrimination performance when the SVM is applied with the sentences from the students who chose the correct answer, ③, used as positive samples; and the sentences from the remaining students as negative samples. The x-axis represents the number of words, *N*, for vectorization. We used *C*=100 for the SVM *C* parameter. The discrimination performance decreases while *N*=9, but otherwise increases with *N*. The highest discrimination performance is observed at *N*=40, where almost all words are used. This means that students who chose the correct answer, ③, have diverse expressions and their comments cannot be represented with only a few patterns.

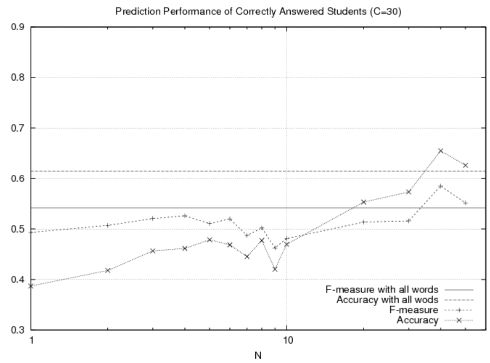

Figure 4. Prediction performance of correctly answered students.

Table III shows the top 20 positive and negative feature words of the students who chose the correct answer, ③.

TABLE III. POSITIVE AND NEGATIVE FEATURE WORDS (CORRECT ANSWER)

	POSITIVE FEATURE WORDS			NEGATIVE FEATURE WORDS		
k	score	df	word	score	df	word
1	1.5481	9	out	−1.8315	11	center
2	1.4733	11	when	−1.784	3	where
3	1.4563	2	part	−1.223	10	for
4	1.3879	7	happen	−1.2211	2	change
5	1.3626	2	done	−1.1756	13	YOU
6	1.3565	3	understand	−1.0556	7	when
7	1.3448	5	material	−0.9453	5	axis
8	1.3413	7	refract	−0.8999	2	air
9	1.2768	9	air(KI)	−0.8709	60	do
10	1.1153	6	through	−0.6793	14	enter
11	1.0941	2	surface	−0.6735	15	learn
12	1.0714	8	air(KUUKI)	−0.599	4	write
13	1.0277	57	refraction	−0.5147	4	angle
14	0.9828	4	glass	−0.4945	2	figure
15	0.9422	6	degree	−0.4945	2	draw
16	0.9333	5	turn	−0.4554	2	path
17	0.8695	3	science	−0.4554	2	remember
18	0.8049	5	become	−0.4326	5	learn
19	0.8024	7	school	−0.4193	2	go straight ahead
20	0.7728	5	junior high school	−0.3518	2	differ

IV. DISCUSSION

We examined the feature words of sentences describing the correct concept, or the misconception, using machine learning (text mining).

A. *Text Mining Analysis of Descriptions from Students who Selected the Correct Concept*

From the results of text mining the descriptions by the 32 students who selected the correct concept, it was observed that almost all feature words are necessary to improve the discrimination performance. It can be said that they have various understandings. The top 20 feature words are: 1. out, 2. when, 3. part, 4. happen, 5. done, 6. understand, 7. material, 8. refract, 9. air(KI), 10. through, 11. surface, 12. air(KUUKI), 13. refraction, 14. glass, 15. degree, 16. turn, 17. science, 18. become, 19. school, and 20. junior high school (Table Ⅲ). These feature words indicate that "the light refracts at the surface of glass," which means it refracts between the two "materials" ("air" and "glass") of the lens, and that "the incident light and the emitted light which gets out from the lens are refracted at each surface." This is the correct scientific concept as it is intended to be learned by junior high school students. It seems to indicate that these students "understand" this optical phenomenon.

Additionally, students with the correct concept that suggests, 'light refracts twice at the surface of the lens,' deeply understand the concept of refract that suggests, "the light refracts at the boundary between two different 'materials,' 'air' and 'glass.'" With these concepts, it is estimated that they were able to think of the path of light passing through the convex lens.

B. *Text Mining Analysis of Descriptions from Students who Selected the Misconception*

The feature words from the comments of the 62 students who selected the misconception are: 1. center, 2. where, 3. axis, 4. 'yo-u,' 5. learn, 6. textbook, 7. for, 8. middle, 9. air, and 10. focus (Table II). Among these words, "center" and "learn" are considered to mean that these students "learn" in junior high school that the light "refracts" at the "center" of the lens. These misconceptions are likely the result of the students having learned by the drawing method. Furthermore, "air" and "material"—which are feature words of the students who selected the correct concept—cannot be seen. This absence illustrates that recognition of the two media—that is, the refraction—does not come to the minds of these students when considering the convex lens. It is estimated that this misconception has occurred because they were unable to consider the property of the convex lens by using refraction.

C. *Meanings of Feature Words "Understand" and "Learn"*

In this study, two verbs for which the participant is the subject are found among the feature words –"understand," and "learn." "Understand" is a feature word in the correct concept descriptions (Table Ⅲ), and "learn," is found in the misconception descriptions (Table Ⅱ). These two words might be interpreted as follows: Students with the correct concept "understand" what they learned in junior high school.

Conversely, students with misconceptions merely "learned" items in junior high school. This might indicate a difference in the depth of understanding between them. Put differently, because the former understood refraction well, the concept of refraction could be used to correctly consider the path of light passing through a convex lens; while the latter remembered that they "learned" that "light refracts at the center of the lens" from the drawing method, but they may not "understand" refraction well.

In this way, as a result of having misconceptions, refraction occurring between 2 media did not come to mind when considering a convex lens. As such, a difference in the depth of understanding of refraction lead to the misconception that light refracts at the center of the lens. Representing this difference in understanding were feature words identified by machine learning.

V. CONCLUSION AND FURTHER WORK

We asked 104 students to choose one of five diagrams showing the path of light through a convex lens and to write the reason for their selection. Subsequently, we examined the feature words of each description representing either correct concept or misconception by text mining. Sixty-two percent of the students chose the incorrect diagram depicting the light refracting at the center of the convex lens, and 32% of the students chose the correct figure drawing. In the former group, feature words representing the misconception such as "center," and "middle"—which describe that "light refracts at the center of the lens"—appeared. In the latter group, feature words indicating a correct understanding of refraction of light—such as "material," "air," "glass," "refract," and "refraction."—appeared. In addition, the sentences from the correct students contained the word "understand," whereas those from the incorrect students contained the word "learn."

Additionally, there were clear differences in both the number of feature words, and the discrimination performance between the correct and incorrect description sentences. The sentences from the students with the misconception contained a minimum of 16 feature words and resulted in an optimal discrimination rate of 78%. The sentences from the students with the correct concept contained 160 feature words and resulted in an optimal discrimination rate of 65%. Put simply, there were typical patterns in the sentences from the students who chose incorrectly, while the sentences from the correct students had varied expressions.

In the future, it is necessary to increase the number of examinees, conduct experiments on subjects of age (such as general adults), and to verify the results of this study. Currently, we have analyzed descriptions through SVM and attribute selection but have yet to compare it with the results of other methods (such as factor analysis and decision tree). These analytical results would be useful for determining correct concepts and misconceptions using machine learning.

ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant Number 16K04725.

REFERENCES

[1] Y. Adachi, N. Onimura, T. Yamashita, and S. Hirokawa, "Standard measure and SVM measure for feature selection and their performance effect for text classification," Proc. iiWAS 2016, 2016, pp. 262-266.

[2] F. Favale and M. Bondani, "Misconceptions about optics: An effect of misleading explanations?," Proc. SPIE – The International Society for Optical Engineering, 2014. https://doi.org/10.1117/12.2070520

[3] M. F. Masters, T. T. Grove, "Active learning in intermediate optics through concept building laboratories," American Journal of Physics, vol. 78(5), 2010, 013094AJP, pp.485-491.

[4] Ministry of Education, Culture, Sports, Science, and Technology (MEXT), COURSE OF STUDY for Junior High Schools-Science, Tokyo: Dainippon Tosho, 2018, pp, 28-30.

[5] T. Sakai and S. Hirokawa, "Feature Words that Classify Problem Sentence in Scientific Article," Proc. iiWAS2012, 2012, pp.360-367.

[6] D. R. Sokoloff, "Active Learning Optics and Photonics Training Manual," UNESCO, 2006. http://www.light2015.org/dam/LightForDevelopment/activelearning.pdf

[7] M. Taga and T. Onishi, "Misconceptions among University Students Regarding Convex Lenses Caused by the Drawing Method at Junior High Schools," Proc. Pixel2018, 2018, https://conference.pixel-online.net/NPSE/conferenceproceedings.php

[8] D. Thapa, V. Lakshminarayanan, "Light and optics conceptual evaluation findings from first year optometry students," Proc. Vol. 9289, 12th ETOP2014, 2014. https://doi.org/10.1117/12.2070519