doi：10.20776/S13482084-69-P77
千葉大学教育学部研究紀要　第69巻　77～82頁（2021）

Lessons for content delivery with emphasis on elements of Nature of Science in the teaching of middle school science

HUANG YuanLing[1] and OSHIMA Ryugo[2]
[1]Ministry of Education, Singapore [2]Faculty of Education, Chiba University, Japan

Nature of Scienceの要素の強調による理科の深い学びの促進
－中学生を対象とした授業開発と評価－

黄苑菱[1]・大嶌　竜午[2]
[1] シンガポール教育省 [2] 千葉大学・教育学部

The purpose of this study serves as a kick-starter to develop lesson units for authentic science for middle school science. These lessons were developed to deliver content knowledge with emphasis on elements of Nature of Science (NOS). This is a short-term study to research on the feasibility of such lesson units in teaching both content and NOS explicitly. The topics selected for development are Chemical Reactions and Atoms & Molecules respectively. The series of lessons were conducted with two classes of 8th Grade Japanese students. Data, both qualitative and quantitative, was collected through a few ways: lesson observations to assess the viability of the lesson; pre- and post-test to evaluate students' understanding of NOS; and questionnaire to gather students' perceptions of the lesson. From the observations of the classes, students were engaged in carrying out the activities to elicit NOS elements. In addition, from the results of the pre-test and post-test, there was an improvement in the understanding of elements of NOS. Furthermore, from the results of the questionnaire, the lesson units were well-received by the students and students were able to learn both content and elements of NOS. These results showed promise in the teaching both syllabus content and elements of NOS in an authentic context.

本研究の目的は，理科の深い学びの促進を指向して，科学的リテラシーに含まれるNature of Science（NOS，科学の性質）の要素を強調した授業を開発すること，及びその開発した授業を評価することである。中学２年生の「化学変化」と「原子・分子」の２つの単元を題材として，それぞれ，科学的知識の可変性，科学的知識の創出における創造性の重要性という，NOSの要素を強調する授業を開発した。主に，当該授業についての感想，授業前後の生徒のNOSの理解度が，質問紙によって問われた。分析の結果，NOSの要素を理科の内容領域の指導に組み込むことで，NOSの理解度の向上に加え，理科の内容についての深い学びを促進できる可能性が示唆された。

キーワード：Nature of Science（科学の性質），真正な科学（Nature of Science），
科学的リテラシー（scientific literacy）

1. Introduction

In the volatile, uncertain, complex and ambiguous (VUCA) world, there is an influx of information and students face the problem of discerning information from this VUCA world. Often, students are easily misled by incomplete or erroneous information (McComas, 2017). Thus, it is important to equip our students with 21st Century Competencies (Ministry of Education, Singapore, 2018). Science education plays an important role in developing a scientific habit of mind, and in turn, nurture scientific literacy in our students.

To develop scientific literacy among students, an authentic science, or at the very least, authentic view of science should be taught in science education. Traditional, or didactic learning environments where the teacher holds the main role of information dissemination (or content download) does not provide opportunities for our students to experience how science is done. Activities such as inquiring, planning and conducting investigations, deriving conclusions, and presenting research findings are often not present or lacking in such learning situations (Lee & Songer, 2003). However, research has shown that children also failed to develop meaningful understanding of scientific enterprise under 'doing science'. Namely, such an understanding is needed to be taught explicitly and teaching Nature of Science (NOS) has come to recent prominence. Many countries have included NOS in science education (Boujaoude, 2002) to nurture 21st

連絡先著者：大嶌　竜午　ryugo.oshima@chiba-u.jp

Century skills such as critical thinking in students (Yacoubian & Khishfe, 2018).

However, it is noted that there are many stakeholders, such as students, parents, scientific community, industry, etc. in science education of which have different goals, values and interests (Gaskell, 1992). Given the limited amount of time, science educators have to teach content and prepare the students for standardised assessments of which often have high stakes. To balance the importance of performance results and to teach authentic science, and in turn develop scientific literacy, activities that could elicit authentic science should be done in class.

According to Holbrook & Rannikmae (2007), "it is necessary to relate scientific literacy to an appreciation of the nature of science, personal learning attributes including attitudes and also to the development of social values". Thus, it is plausible to provide authentic science by emphasising on NOS.

2. Aim

The objective of the study is to develop lesson units for daily content delivery while emphasising the elements of NOS. This is a short-term study to research the feasibility of such lesson units in teaching both content and NOS. If such lessons proved to be effective, and all lessons throughout the year are to be carried out as such, the teaching of authentic science and in turn the development of scientific literacy can be achieved.

3. Method

3.1 Participants

The lesson units were conducted for two classes of 8^{th} Grade students in Japanese. 72 students completed the pre-test while 70 students completed the post-test.

3.2 Lesson Units

The following points were considered when designing the lesson units:

1) The lesson must provide learning in an authentic context.
2) The lesson should serve as a simulation of the activities performed by scientists in the process of producing scientific knowledge.
3) The lesson should give students opportunities to perform practical activities/hands-on activities.

Historical events were incorporated to set an authentic context in a lesson because historical events as science enterprise must include realistic understanding about science and scientists and; they convey certain important ideas about science and scientists (Klopper & Cooley, 1963) which are NOS elements. As the aim of the lessons is not only to teach NOS but also science contents, practical activities were also prepared. Students were expected to do practical activities based on historical events and appreciate the elements of NOS relating to the science content while studying the both the content and elements of NOS in an authentic context.

to study science content in an authentic context and to study elements of NOS.

The following topics were selected for the development of the lesson units.

1) Chemical reactions → Phlogiston theory

The first lesson unit (3 sessions, 50 min each) was developed, referring to Takami and Kinoshita (2017). It involves conducting of an experiment to verify the erroneous Phlogiston Theory and how this was superseded due to the discovery of oxygen gas. The lesson unit ended with the explicit teaching of the NOS element: scientific knowledge is simultaneously reliable and yet tentative.

2) Atoms and Molecules → Mendeleev's periodic table

The second lesson unit (1 session), involves a short hands-on activity where each group of students will be given a set of polygon shapes (14 out of 16 shapes consisting of 4 different shapes, each of 4 different sizes) to be arranged in any form of their choice. As there are several possible arrangements, the activity serves to bring out the point that creativity is crucial in the production of scientific knowledge.

3.3 Feedback and Evaluation

To evaluate the effectiveness of the lesson units, two questions adopted from View of Nature of Science Questionnaire (VNOS) Version D+ (Lederman, et al., 2002) will be used as pre-test and post-test. Students' answers were first translated from Japanese to English, then classified according to "Yes/No" response, followed by categorisation in terms of types of examples given.

In addition, a questionnaire using the Likert scale to gather feedback from students regarding the lessons carried out will be administered. The scale used was: 1 indicating 'Strongly Disagree'. 2 indicating 'Disagree', 3 indicating 'Neutral', 4 indicating 'Agree' and 5 indicating 'Strongly Agree'.

4. Results

4.1 Lesson observations

4.1.1 Chemical Reactions – Combustion

This lesson unit consists of 3 sessions (each session is about 50 minutes). The teacher started the first session with the history of Chemistry, (known as alchemy then) and how there were initially thought to be only four elements that existed in the world (classical elements). This served as a basis for the introduction of the erroneous Phlogiston Theory which claimed that fire-like substance called "phlogiston" would be released from combustible materials when burnt. Upon the introduction of phlogiston, students expressed interest in this "new" concept as they were observed asking for more clarification in class. The students were then given the task to discuss possible methods to verify the validity of Phlogiston Theory within their groups while the teacher walked around facilitating the discussion. From observations, students were actively participating in the discussion. Some proposed methods given by the students were as follow: 1) to investigate the substance released from combustion; 2) to compare the mass of substance before and after combustion; and 3) to compare the mass of phlogiston with air and air only. It was interesting to note that a student questioned the Phlogiston Theory by using the burning of dry ice as an example as the theory seemed only applicable to substances that leave behind ashes after burning. This showed that the student was actively involved in the lesson. After the discussion within the groups, the students were then to share their ideas with the class. The teacher then facilitated the selection of method (method 2 was chosen) and development of experiments to be carried out in the second session.

The second session followed the Predict-Observe-Explain (POE) routine. Students were to predict the experimental outcomes based on Phlogiston Theory. They were to burn disposable wooden chopstick and steel wool separately and compare the mass of the substance before and after burning. After the safety briefing, each group of students commenced the experiment. From observations, students enjoyed carrying out these experiments very much and that all the students had a clear idea of the purpose of the experiment being carried out.

The results showed that the burning of chopstick supported Phlogiston Theory while that of steel wool contradicted. In the spirit of authentic science, students were given time to discuss reasons for such discrepancy and propose improvement to experiments while the teacher walked around the class to facilitate the discussion. Students suggested that the experiment might not be a fair test and improvements to the current method was suggested. The session ended with the proposal to conduct the experiment in a closed system in the next session. It was observed that the students appeared to be partial to group discussions and benefitted from them.

The third session began with a safety briefing by the teacher before the student conducted the experiment of heating the chopstick and steel wool separately, in a sealed round-bottomed flask. This experiment took a longer period of time to complete than expected due to the requirement to cool the flask before weighing. The results once again showed discrepancy with Phlogiston Theory proving that it was erroneous. The teacher then rounded up the lesson unit with the teaching of content that combustion requires oxygen gas and also the NOS element that Science is reliable and at the same time, tentative.

4.1.2 Atoms & Molecules

This lesson unit consists of 1 session (50 minutes) and started off with the introduction of the concept of atoms and elements. Following that, a brief introduction of the modern Periodic Table which owed its conception to Russian Chemistry Professor Dmitri Mendeleev who organised the elements into a table. Students were then given the task to arrange 14 out of 16 polygons shapes in any "rule" or manner of their choice. The 16 polygon shapes consist of 4 shapes: triangle, square, pentagon, hexagon. Each shape has 4 different colours and relative sizes. Each size of the shapes is not allocated the same colour (see Figure 1). This was done in the spirit of authentic science, to simulate what Mendeleev had experienced when constructing his periodic table as there were elements that were yet to be discovered then. As there were 2 missing polygon shapes (the students were not informed of the missing pieces), the arrangement required the students to be creative in their thinking and being able to observe trends. It was observed that students were actively participating in this activity and discussions on the method of arrangement were evident in the groups.

There were both simple and complex rules of arrangement proposed. Students who thought more simply tend to arrange the polygons by one parameter or a combination of two parameters: their shapes (number of sides), colours or sizes (figure 1). It was interesting to note that 6 out of 18 groups of students gave more consideration to the different parameters of the polygon shapes. Out of these 6 groups, 2 groups of students were able to apply higher order thinking skills and arranged the table with all three parameters. They also took the unknown missing pieces (figure 2) into consideration through identifying patterns and leaving spaces for them in the arrangement.

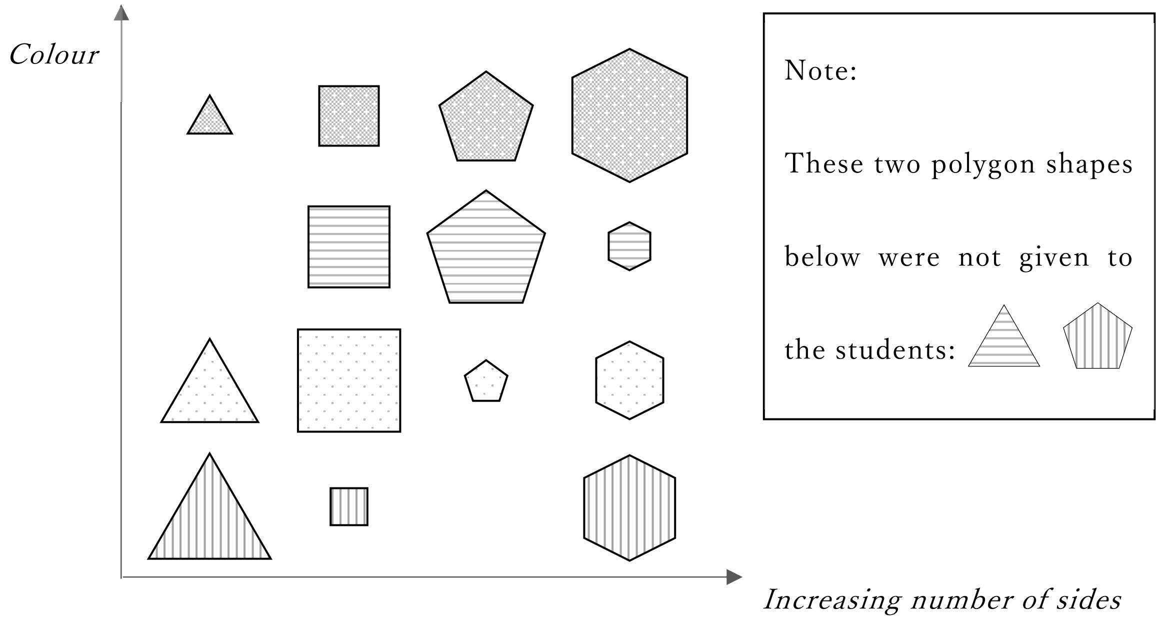

Figure 1: Sample answer (simple) from students

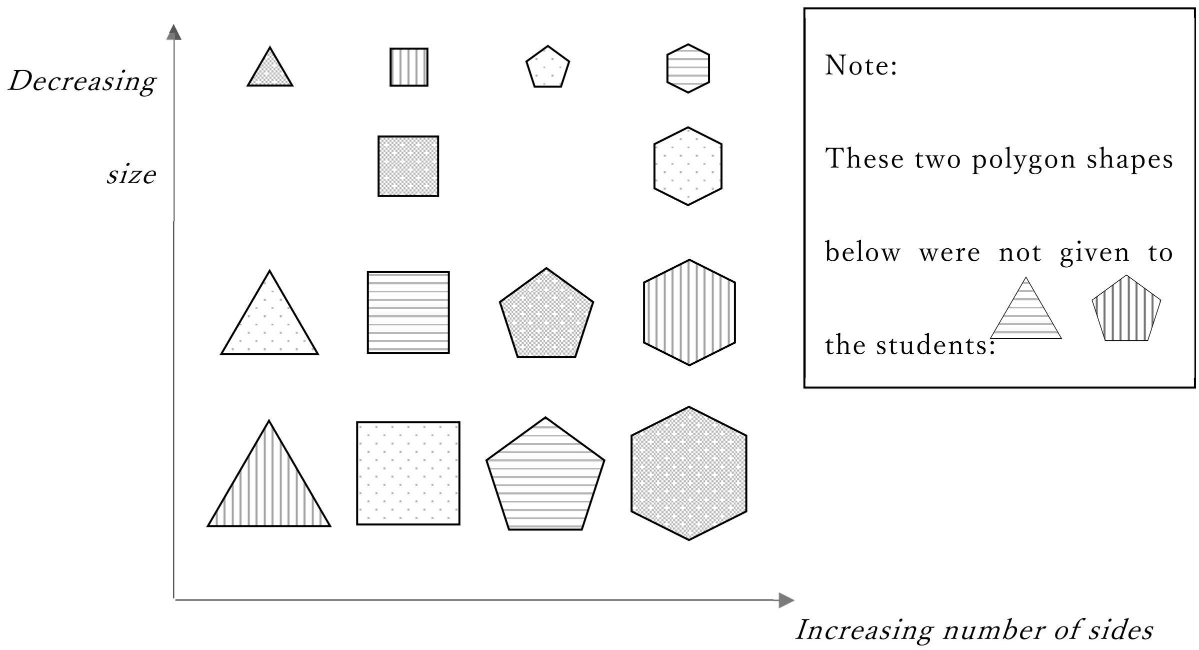

Figure 2: Sample answer (complex) from students

The students then shared their rules of arrangement with their classmates and many students were surprised by the various different ways in which the same set of polygon shapes could be organised. The sharing was done to illustrate the point that imaginative skills (creativity) is present in the science and also to experience what Mendeleev could have gone through in creating his periodic table. The fact that Mendeleev had placed unknown elements (elements that were not yet discovered at that time) in his periodic table by taking into account trends and predicting the properties of these unknown elements were also brought up in class to further demonstrate the necessity of creativity in the production of scientific knowledge. Although this lesson unit was meant to be carried out within one session, the explicit teaching of NOS element was done at the beginning of the next lesson as the arrangement of the polygon shapes and discussion and sharing took more time than expected.

4.2 Pre-test and Post-test

Question 2 and Question 3 served to check the students' understanding of NOS elements which are 'Scientific knowledge is simultaneously reliable and yet tentative as it may be abandoned or modified considering new evidence and knowledge' and 'Creativity is a vital, yet personal, ingredient in the production of scientific knowledge'.

In Pre-test Question 2, although 80.3% of students agreed that scientific knowledge is subjected to change, many could not give any examples. Those who could, gave examples such as the geocentric model being superseded by the heliocentric model and; that of the Earth being thought as flat in the past. Only 8.8% of the those who agreed, answered that scientific knowledge changes due to the emergence of new evidence made possible by advancement of technology although no examples were provided.

In Post-test Question 2, there is an improvement in the percentage of students who agreed (88.6%). 8.1% of students who agreed were able to give Phlogiston Theory as on example and a slightly higher percentage (13.0%) of students could relate the change in scientific knowledge to emergence of new evidence although the lack of example is still prevalent.

From Pre-test Question 3, 87.3% of students believed that imagination is present in various aspects of scientific investigations. 59.7% of these students indicated that imagination is necessary in the planning of an experiment. However, there were considerably fewer students who thought that imagination is also necessary in other aspects of scientific investigations. In addition, 96.8% of students who agreed could not give any example. This is mainly because 1) students were not taught explicitly elements of NOS prior to the lessons being conducted and were not able to link relevant prior knowledge to answer such question and; 2) misinterpretation of the question. All students assumed that they were to specify the aspect(s) of the scientific investigations where creativity and imagination were showed and to give scenarios to substantiate their answers.

The results from the Post-test Question 3 (91.4% agreed) suggest that students were certain of the necessity of imagination in the production of science. Similar to the pre-test, there was a relatively small number of students who indicated that imagination is required in other aspects of scientific investigation, aside from planning although there was greater awareness of its necessity in all aspects of scientific investigation.

In addition, similar to the Pre-test, students specified the aspect(s) of the scientific investigations and most failed to substantiate their answers with relevant examples. Only 3.1% of the students who agreed could provide concrete examples such as Mendeleev being able to organise elements, both discovered and undiscovered at that time, by observing trends and predicting their properties in a table.

4.3 Questionnaire

The questionnaire (table 1) used the Likert scale with 1 indicating 'Strongly Disagree (SD)'. 2 indicating 'Disagree (D)', 3 indicating 'Neutral (N)', 4 indicating 'Agree (A)' and 5 indicating 'Strongly Agree (SA)'.

Table 1: Selected questions of questionnaire

Q	Focus
1-1	Enjoyment level of the class (Combustion)
1-5	Being actively involved in learning (Combustion)
1-9	Level of understanding: oxygen is necessary for combustion to occur
2-1	Enjoyment level of the class (Atoms and Elements)
2-6	Being actively involved in learning (Atoms and Elements)
2-9	Level of understanding: elements in the Periodic Table are arranged according to their properties
3-2	Creativity is essential in the production of scientific knowledge
3-5	Scientific knowledge are not absolute facts, they may be changed.

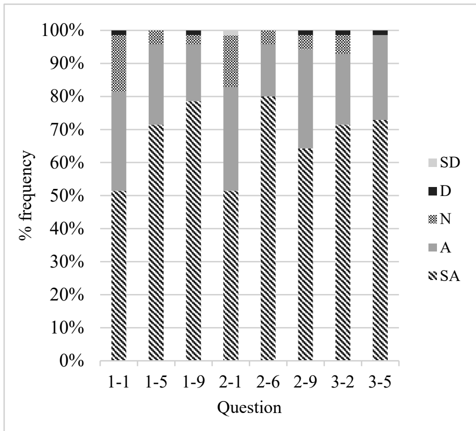

Figure 3: Percentage frequency of selected questions from questionnaire

From the results of the questionnaire (figure 3), students were very receptive to the lessons conducted as seen from Q1-1 and Q2-1. The lessons also proved to be engaging as seen from the scores of Q1-5 and Q2-6. In addition, the lessons served both the purpose of delivering class content and also the teaching of NOS elements as seen from the high scores of Q1-9, Q2-9, Q3-2 and Q3-5.

From the response in the comment section, most students found the lesson units interesting and engaging as students could grasp the concepts taught through experiment. These lesson units were conducted in an easy-to-understand manner through experiments and activities to teach Chemistry in ways relatable to student. It also provided opportunities for students to learn more deeply and meaningfully.

Student 1: I want to conduct more experiments that do not have a definite answer or a definite outcome as given by the teacher. I want to conduct experiments that I am not sure of (novel, unpredictable). By doing so, I can reflect on my errors, consider ways to rectify the error or to prevent it from happening again, and in turn, deepen my own learning.

Student 2: The periodic table was a very meaningful lesson, especially because I thought about it independently, formed my own opinions, and deepened each other's understanding.

The reiteration of NOS elements by the students was also seen in the comments section. Students wrote about gaining more interest in Science due to learning that "established facts" can be refuted in the future when new evidence arises and how Mendeleev could predict properties of undiscovered elements in his Periodic Table using imagination (and creativity).

5. Conclusion

Elements of NOS can be taught in conjunction with, and throughout the science curricula. This allows students to assimilate NOS and the scientific content (as stipulated by the syllabus), when constructing their own scientific knowledge. In addition, it is possible to contextualise NOS elements in the everyday teaching and learning of Science through activities and/or experiments that could illustrate these elements. The lesson units were made more meaningful when there is authentic view of science present in the activities carried out.

From this research, it can be concluded that elements of NOS can be effectively taught in class with little time taken away from teaching syllabus content. This article can serve as an idea in developing lessons with elements of NOS to bring about a more authentic science education and to develop scientific literacy.

References

Boujaoude, S. B. (2002, February). Balance of scientific literacy themes in science curricula: The case of Lebanon. International Journal of Science Education, 24(2), 139-156. Retrieved from https://www.researchgate.net/publication/248974454_Balance_of_scientific_literacy_themes_in_science_curricula_The_case_of_Lebanon

Eastwell, P. (2002). The Nature of Science. The Science Education Review, 1(2), 43-48.

Gaskell, P. J. (1992). Authenic science and school science. International Journal of Science Education, 14(3), 265-272.

Holbrook, J., & Rannikmae, M. (2007). The Nature of Science Education for Enhancing Scientific Literacy. International Journal of Science Education, 29(11), 1347-1362.

Klopfer, L. E. & Cooley, W. W. (1963). The histor of science cases for high schools in the development of student understanding of science and scientists: a report on the HOSC instruction project. Journal of Research in Science Teaching, Vol.1, pp.33-47.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., Schwartz, R. S., Lederman, J., & Ko, E. K. (2002). View of Nature of Science Questionnarie (VNOS) Version D+. Retrieved from PhysPort: https://www.physport.org/assessments/assessment.cfm?A=VNOS&S=2

Lee, H.-S., & Songer, N. B. (2003). Making authentic science accessible to student. International Journal of Science Education, 25(8), 923-948.

McComas, W. F. (2017, June). Understanding how science works: The nature of science as they foundation for science teaching and learning. The School Science Review, 98(365), 71-76.

Ministry of Education, Singapore. (2018, Oct 11). 21st Century Competencies. Retrieved from Ministry of Education, Singapore: https://www.moe.gov.sg/education/education-system/21st-century-competencies

National Science Teacher Association. (2000, July). NSTA Position Statement - Nature of Science. Retrieved from National Science Teacher Association: https://www.nsta.org/about/positions/natureofscience.aspx

Takami, K. and kinoshita H. (2017). The development and evaluation of a science teaching method to promote critical thinking through interactions with others-from classroom practices in the unite "chemical change" in lower secondary school science-. Journal of Research in Science Education, Vol.58, No.1, pp.27-40.

Yacoubian, H. A., & Khishfe, R. (2018). Argumentation, critical thinking, nature of science and socioscientific issues: a dialogue between two researchers. International Journal of Science Education, 40(7), 96-807.