In this study, a lesson model related to the phenomenon of the rusting of iron was developed to confirm the effect of modeling by drawing on the understanding of chemical reactions. The model was applied in the non-science course “Science study (chemistry)” classes comprising third-year undergraduate students in Tokyo Gakugei University. Students constructed images of the rusting of iron, in addition to attending lectures with frequent discussions, without any prior written communication to students, as well as taking notes, and the students completed the subsequent process of drawing as well as its explanation. Students drew pictures with their own images and explained their drawings appropriately as per their own understanding of chemical concepts and the phenomenon at hand. By the evaluation of the lesson model via the lesson of an “activated complex” as a representative of the model by the process of drawing and self-explanation, as well as an intelligibility test, students could understand chemical concepts and images of the rusting of iron by actually drawing, i.e., the task of drawing could strengthen the student’s explanatory ability and intelligibility about the rusting of iron; in particular, it was effective for intelligibility even for students who obtained a low score of 0 points, besides the limitation of the effect on reinforcement of explanatory capability of the phenomenon for the 0 points score students, suggesting that learning with imaginative thinking and behavior is imperative for students to understand chemical reactions by evaluation.

Key words: modeling, lesson model, chemical reaction, drawing, images
Effect of Modeling on the Understanding of Chemical Reactions via Development and Application of a Lesson Model Related to the Rusting of Iron

On the other hand, with respect to research of modeling or making of models in Japan, activities relating a model to a new unknown phenomenon as well as making a model to explain it have been continuously utilized in scientific methodology (Okitsu, Takeda and Tokyo creation science member, 1969). Several studies have been reported about an electric current model (Nagai and Kawakita, 1999; Masuda, 2006; Uchinokura, 2008) and a particle model (Onose, Fujieda, and Morimoto, 2009; Yamashita and Onodera, 2009; Minezaki, Kubota, and Kobayashi, 2011), as well as the relation between model and analogy (Uchinokura, 2010). These studies made educational guidance of a model or modeling their subject.

We conducted a survey of the science textbooks currently used to teach primary and junior high schools as well as Chemistry I and II (Dainihon-tosho, 2003; Keirin-kan, 2003; Tokyo-shoseki, 2003) in senior high schools based on the Japanese study course (MEXT, 1999). Our survey of chemistry textbooks in Japan revealed that their contents are grouped by knowledge of boldface transcription (Ogawa, Okada, Takehara, & Ikuo, 2006), skills for experimental study (Ogawa, Takano, Ikuo, Yoshinaga, and Fujii, 2009), and schemes as examples of images (Ogawa, Ishiwaki, Ikuo, Yoshinaga, and Fujii, 2008). The survey suggested that knowledge, skills, and schemes are distinctly described based on the Japanese course of study for the purpose of teaching and learning.

The promotion of creativity in science has been reported and discussed previously (e.g., Höhn and Harsh, 2009; Jarvis, 2009; Longshaw, 2009; Ohshima, 1920). It is imperative for students to be able to think and act imaginatively (Wardle, 2009). Our interest lies in the improvement of science and chemical education where lessons require dialogue between students and a teacher, a minimum time commitment, and independent study by students. We have introduced a fundamental feature in school lessons in science and chemistry, Special Emphasis is Placed on Imagination Leading to Creation (SEIC) (Ogawa, Fujii, and Sumida, 2009), where a phenomenon created by a student’s imagination is specifically attributed to a new idea of creative thinking about an object of the phenomenon. Through the SEIC program, participants used several chemical terms in explanations and appropriately explained their own understanding of drawings (Ogawa and Fujii, 2013). In this paper, a lesson model is developed on the rusting of iron, and the effect of modeling on the understanding of chemical reactions is observed.

II. Development of the lesson model

Student-initiated activities such as brainstorming and self-work activities are imperative for making this lesson model. The lesson specifically emphasizes the enhancement of imagination via tasks primarily involving drawing and/or self-explanation. Gilbert, Boulter, and Elmer (2000) have emphasized the standpoint of modeling, as mentioned in point 1) in the Introduction. This lesson model is expected to be beneficial as clearer images can enhance the understanding of the chemical reactions with certain chemical concepts by good use of thought, ability for expression, and reason. The lesson model is also expected to increase the power of imagination, accompanied with sufficient knowledge obtained as a tool.

1. Lesson model

The lesson model developed here consists of three lessons for students to understand chemical reactions associated with the rusting of iron, which is a typical, popular phenomenon even in school chemistry. Fundamental content or lesson topics are typically chosen in terms of basic chemistry, that is, chemistry is approximately composed of three frames: structure, equilibrium, and change. This lesson model moderately covers equilibrium and change, i.e., stoichiometry, activated complex, and entropy change leading to the Gibbs function.

The first lesson of learning “stoichiometry” includes the chemical concepts of reactants and products, energy state, heat of reaction, and enthalpy. Learning “chemical bonds” had been already introduced before this lesson model with concepts such as electronegativity, potential energy, ionic bond, covalent bond, coordinate bond, metallic bond, hydrogen band, and van der Waals interactions.

The second lesson involves the learning of an “activated complex,” which includes physical quantities such as activation energy $E_A$ and enthalpy change $\Delta H$, and Section II.2 describes the details.
The final lesson of learning involves the “entropy” change, which includes physical quantities such as entropy change $\Delta S$ and Gibbs energy change $\Delta G$. This is followed by advances, such as generalizing the lesson model for understanding chemical reactions by considering a possible reaction path of the rusting of iron rust via making a model of a possible activated complex by considering physical quantities studied previously (such as $E_a, \Delta H, \Delta S$, and $\Delta G$).

2. Case of the lesson of “activated complex”

An activated complex is one of the important concepts for understanding chemical reactions in chemistry. By modeling of a possible activated complex, a possible reaction path for the rusting of iron is considered. In this paper, the lesson is used as a representative of the lesson model for evaluation. The lesson includes the following contents:

1) Lecture and discussion, e.g., considering the reaction of water generation;
   a) Expectation of an activated complex (dissociation and recombination),
   b) Making a reaction path diagram including the activated complex,
   c) State of the chemical reaction (direction, quantity: chemical equilibrium, and velocity: activation energies), and
   d) Catalysis.
2) Application of the rusting of iron;
   a) Drawing of an activated complex during the rusting of iron,
   b) Construction of the reaction path diagram, and
   c) Self-explanation of the rusting of iron rust.

In the lecture on water generation, the generation of water by the dissociation of a covalent bond, occurrence of recombination, and the inevitability of the existence of the activated complex with an unstable energy state are discussed based on eq. (1), and the reaction path (diagram) of water generation is confirmed.

$$2\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(l); \Delta H_f^\circ = -285.8 \text{ kJ mol}^{-1} (298\text{K}); \Delta G_f^\circ = -237.2 \text{ kJ mol}^{-1} (298\text{K}). \quad (1)$$

Students advance to the next step by applying these outcomes to the rusting of iron by eq. (2).

$$4\text{Fe}(s) + 3\text{O}_2(g) + 6\text{H}_2\text{O}(l) \rightarrow 4\text{Fe}(\text{OH})_3(s); \quad \Delta H_f^\circ = -823 \text{ kJ mol}^{-1} (298\text{K}); \quad \Delta G_f^\circ = -697 \text{ kJ mol}^{-1} (298\text{K}). \quad (2)$$

In reality, the lesson is performed by the following contents of a possibly reaction path constructed using a model of a possible activated complex, where the 1) direction of the reaction, 2) degree of reaction progress (chemical equilibrium) based on $\Delta H$, and 3) reaction velocity based on $E_a$ are introduced. The lesson included chemical concepts such as acquisition of knowledge by designated chemical terms within the limits stated in the self-explanation sheet (Appendix 1).

3. Timetable

Typically, the lesson is divided into five activities as described below.

The first 10 min of the lesson is spent in reviewing the previous lesson by using samples of the pictures drawn by students under the lecturer’s guidance.

The next 45 min is utilized for the lecture, with particular emphasis on operations of the brain such as discussion, brainstorming, and recitation under the teacher’s guidance, without competition in a class where students use only their own thinking. These processes enable students to develop essential knowledge and skills while simultaneously comparing the activities and opinions of others with their own. Students’ attentiveness is also promoted by the next step of drawing.

The third step involves 10 min for providing students with an opportunity to memorize.

The fourth step consisting of 15 min is focussed on drawing pictures on the problem posed by the lecturer. Students’ understanding of certain chemical concepts or phenomena is expressed in these drawings, and sometimes their own explanations are written outside the drawing area using chemical terms. Student-initiative operations are followed
by lessons; these lessons specifically emphasize students’ work, which helps students’ concentration.

In the final 10 min of the lesson, students explain their pictures or other work on a self-explanation sheet (Appendix 1) by optimally utilizing their knowledge of chemical terms. The explanation should indicate sufficient knowledge of the lesson’s objectives regarding chemical concepts and phenomena. Thus, the lesson fosters creativity by thinking, expression, and reasoning.

III. Practice of the lesson model

Three lessons were carried out in two “Science study (chemistry)” of non-science course classes comprising 43 and 49 undergraduate students of junior (third-year) level in Tokyo Gakugei University (TGU) in the fall semester of 2014. The lessons were applied and revised during 6 years from 2009 to 2014. The lesson time was approximately 90 min each.

The task of constructing images of certain chemical concepts and the rusting of iron was performed through the lesson, basically followed by discussion and students’ work. For example, in the lecture on water generation in the lesson of the “activated complex,” the generation of water by the dissociation of a covalent bond, occurrence of new combination, and the inevitability of the activated complex of an unstable energy state were discussed, followed by the final presentation of the confirmed reaction path (diagram) of water generation. Students drew pictures and explained with attentiveness the problem posed by the lecturer. Drawings include descriptions of text, marks, lines, arrows, and illustrations with written explanations outside the drawing area on a sheet using chemical terms indicated by a division line. Figure 1 shows examples of student drawings of an activated complex. Drawings featured several representations and vivid descriptions. Students’ understanding of certain chemical concepts and phenomena were expressed in drawings, and sometimes, their own explanations were written outside the drawing area, utilizing several of the chemical terms obtained from the lecture. In subsequent self-explanations, students could adequately explain their own understanding of drawings on the self-explanation sheet (Appendix 1), where several chemical terms and chemical concepts were used in each document for explaining the phenomenon.

IV. Evaluation of the lesson model

The lesson model is evaluated by the lesson of the “activated complex” as a representative in two classes, where student’s work of drawing and self-explanation, or the intelligibility test, were assessed from two aspects, activated complex and reaction path, involved with the rusting of iron.
The timetable was rearranged as follows; the first 10 min of the lesson in reviewing was adjusted to 2 min. Both drawing and self-explanation were conducted in a class with 43 students in the following order: 1st self-explanation (10 min), drawing (13 min), and 2nd self-explanation (10 min) after the review (2 min), lecture (45 min), and memorization (10 min). Drawing and the intelligibility test were conducted in another class with 49 students in the following order: 1st test (10 min) before the lesson in advance, 2nd test (10 min), drawing (13 min), and 3rd test (10 min) after the review (2 min), lecture (45 min), and memorization (10 min).

1. Scoring rule
   All evaluations were estimated by a perfect score of 5 points.
   a. Drawing
      A drawing rule was set up as a standard, where drawings should be sufficiently attractive for everybody to view them again. Rules with respect to drawing in the drawing area were regulated, e.g., letters, marks, lines, arrows, and illustrations in similitudes, while the text style using chemical terms could be explained outside the drawing area by a division line. A B6 size drawing sheet was used.
      In the drawing sheets, drawing was divided into left and right parts consisting of 1) a structure image of an activated complex and 2) a reaction path, respectively. The evaluation standard is as follows:

      1) Structural image of the activated complex: 3 points:
         a) possible dissociation and recombination (+2 points) and b) expression of a compound by relating it to the iron element particles (+1 point),
      2) Reaction path: 2 points; a) energy level difference in the presence of a catalyst (+1 point) and b) energy levels of reactants, activated complex, and products (+1 point), violation of the rule (−1 point).

   b. Self-explanation
      Students could adequately explain their own understanding of the drawings on the self-explanation sheet (shown in Appendix 1), where several chemical terms and chemical concepts were used in each document for explaining certain chemical concepts or phenomena.

   Concise explanation was required with respect to the activated complex as a compound (+1 point), dissociation and recombination (+1 point), and reaction path (+3 points) [a) direction, b) quantity of products, c) reaction velocity; 1 point for each of the items a), b), or c].

2. Intelligibility test
   Students had to attempt this test for checking intelligibility in the lesson, which comprised five questions (Q) with each one having a score of 1 point (Appendix 2).

2. Results from the achieved score
   a. From drawing
      Figure 1 shows an example of the scoring rule, in which drawings (a), (b), and (c) were marked with scores of 5 (3, 2), 4 (3, 1), and 3 (1, 2), respectively. The values in parentheses indicate the score from either 1) structural image of the activated complex or 2) reaction path. Drawing (a) was perfect, when 1) structure image a) of possible dissociation and recombination (+2 points) and b) of expression of a compound by relating it with iron element particles (+1 point) and 2) reaction path a) of the energy level difference in the presence of a catalyst (+1 point) and b) of energy levels of reactants, activated complex, and products (+1 point) were well described. Drawing (b) was marked −1 point on 2-a), attributed to the inaccuracy about the energy level difference in the presence of a catalyst. Drawing (c) was marked −2 points on 1-a), attributed to the inaccuracy of the possible dissociation and recombination.
      Table 1 shows the distribution of the scores obtained from drawings. A mean score of 2.9 points was recorded with the highest frequency of 26%, and 1.3 and 1.4 points were recorded for the structure and reaction path, respectively. By contrast, the reaction path was accurately represented; however, the structure was not always drawn appropriately. In particular, it was difficult to represent dissociation and recombination, implying that drawings that did not utilize letters, marks, lines, and arrows as mentioned in the drawing rule are somewhat difficult for these students as compared with those utilizing them.

   b. From self-explanation
      Table 2 lists the distribution of scores obtained from
self-explanation. Mean scores of 1.9 and 2.9 points were given to preliminary and posteriori surveys, respectively, and each low score shifted overall to a high score by an individual between 0 and 4 points according to the change of negative $\Delta$ values to positive values. This revealed that drawing is effective for almost all students, except those getting 0 point score on self-explanation for the image of the activated complex. However, still 9% of students scoring 0 points remained. These students also comprised 11% of those scoring 0 points by drawing, as shown in Table 1, indicating that these students possibly exhibit low explanation capability because of the weak capability of drawing. On the whole, these students represented those that were not aggressive with the lesson. These seems to be a limitation of the effect of drawing on an increase in reinforcement of explanation capability to the phenomenon of iron rust for the students getting 0 points score.

Table 1. Scores obtained from drawing*  

<table>
<thead>
<tr>
<th>Score</th>
<th>Distribution/%</th>
<th>Total</th>
<th>Structure</th>
<th>Reaction path</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>23</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>17</td>
<td>23</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>19</td>
<td>23</td>
<td>14</td>
<td>37</td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>14</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>14</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>mean'</td>
<td>2.9</td>
<td>1.3</td>
<td>1.4</td>
<td></td>
</tr>
</tbody>
</table>

* The lesson of the “activated complex,” 43 persons.  
* Full marks (Total: 5 points; Structure: 3 points, Course: 2 points).  
* Average point.

Table 2. Scores obtained from self-explanation*  

<table>
<thead>
<tr>
<th>Score</th>
<th>Distribution/%</th>
<th>Pre-</th>
<th>Post-</th>
<th>$\Delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>14</td>
<td>12</td>
<td>+12</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>25</td>
<td>14</td>
<td>+14</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>23</td>
<td>2</td>
<td>+2</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
<td>14</td>
<td>–12</td>
<td>–9</td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>12</td>
<td>–9</td>
<td>–7</td>
</tr>
<tr>
<td>0</td>
<td>16</td>
<td>9</td>
<td>–7</td>
<td>–7</td>
</tr>
<tr>
<td>mean'</td>
<td>1.9</td>
<td>2.9</td>
<td>–7</td>
<td>–7</td>
</tr>
</tbody>
</table>

* The lesson of the “activated complex,” 43 persons.  
* $\Delta = (\text{post-}) – (\text{pre-})$.  
* Average point.

Table 3 lists the details of the scores obtained with respect to the structure and reaction path. The low scores from 0 to 1 points for both structure and reaction path were shifted to high scores marked positive $\Delta$ values, implying that the explanation is strengthened by drawing, besides acquiring knowledge from the lecture.

Table 3. Scores obtained from two viewpoints on self-explanation*  

<table>
<thead>
<tr>
<th>Score</th>
<th>Structure</th>
<th>Reaction path</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-</td>
<td>Post- ($\Delta$)</td>
<td>Pre-</td>
</tr>
<tr>
<td>3</td>
<td>—</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>47</td>
<td>16</td>
</tr>
<tr>
<td>1</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td>0</td>
<td>25</td>
<td>44</td>
</tr>
</tbody>
</table>

* The lesson of the “activated complex,” 43 persons.  
* $\Delta = (\text{post-}) – (\text{pre-})$.  
* Average point.

Table 4. Scores obtained from the intelligibility test*  

<table>
<thead>
<tr>
<th>Score</th>
<th>Distribution/%</th>
<th>Readiness</th>
<th>Pre-</th>
<th>Post-</th>
<th>$\Delta$</th>
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<tr>
<td>5</td>
<td>0</td>
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<tr>
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<td>33</td>
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</tr>
<tr>
<td>2</td>
<td>41</td>
<td>11</td>
<td>10</td>
<td>–1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>27</td>
<td>6</td>
<td>0</td>
<td>–6</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>18</td>
<td>2</td>
<td>0</td>
<td>–2</td>
<td></td>
</tr>
<tr>
<td>mean'</td>
<td>1.5</td>
<td>3.7</td>
<td>4.1</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>

* The lesson of the “activated complex,” 49 persons.  
* $\Delta = (\text{post-}) – (\text{pre-})$.  
* Average point.

c. From the intelligibility test

The effect of modeling on the understanding of the rusting of iron was observed in the former section b. In this section, the intelligibility of the chemical reaction is analyzed by an intelligibility test (Appendix 2). Table 4 summarizes the distribution of the scores obtained at readiness before the lesson and those of preliminary- and posteriori-surveys concerned with drawing. Low percentage scores were recorded before the lesson, and of course, those shifted to high scores after the lecture during the first half of the lesson, and successively, those shifted to even higher scores. Mean scores of 1.5, 3.7, and 4.1 points were recorded at readiness, pre-, and post-test, respectively. The score after
drawing increased from 3.7 to 4.1, indicating the effectiveness of drawing tasks.

In detail, for students getting high scores of 5 and 4 points, the understanding of the chemical reaction was developed by a lecture from the total value of 0% to 59% (of 37% plus 22%), and after drawing, it significantly increased to 74% (of 41% plus 33%) as shown in Table 4. In the case of scores of 3 and 2 points, understanding was increased with a shift to high scores from a total of 55% to 33% and 26%, respectively. With respect to low scores of 1 and 0 points, corresponding to the understanding developed by a lecture and drawing from 45% to 8% and 0%, respectively, indicating that drawing is effective for all students in terms of the understanding of the chemical reaction. In particular, students still remaining in the 8% bracket of 0 points score were also the students included in the 11% bracket of 0 points score by drawing as shown in Table 1 and 9% of analogs by the self-explanation as shown in Table 2. This result indicated that drawing can result in the acquisition of the concepts of a chemical reaction even for students scoring a 0 point score.

Table 5 lists the percentages of the correct answers to questions from 1 to 5. Questions Q4 and Q5 were comparatively difficult for students, with low values of 12% and 8% at readiness, respectively. After the lecture, the percentages corresponding to Q1 to Q5 were improved, especially Q2 and Q4. By contrast, those corresponding to Q1, Q3, and Q5 were remarkably improved after drawing with marked positive Δ values of +9, +15, and +12, respectively. Q2 and Q3 were related to the direction of the reaction and its reacting quantity, respectively. Q1, Q3, and Q5 referred to the structure, reaction rate, and catalyst, respectively. In other words, Q2 and Q3 were expressed by an equation of the chemical reaction, and Q1, Q3, and Q5 were not expressed by the former equation and would require more conceptual images, indicating that the concepts of a chemical reaction (with relatively simple thinking) acquired could be fitted in with the lecture, and comprehensive utilization of those (with relatively comprehensive thinking) tended to be fitted in with the activity of drawing, i.e., the task was effective in students’ thought of the comprehensive utilization of knowledge and concepts. This lesson model can be one of the candidates for suitable teaching materials when students learn chemical reactions by modeling.

V. Conclusion and Discussions

In this study, a lesson model was developed for the understanding of chemical reactions by modeling. The model was evaluated by the lesson of an activated complex as a representative of the lesson model, and the results obtained indicated that students can understand chemical concepts and images of the rusting of iron by actual tasks of drawing. By drawing and self-explanation and the intelligibility test, students could clarify chemical concepts and images of the rusting of iron by actual drawing, i.e., drawing can strengthen the student's ability to explain and have intelligibility about the rusting of iron, particularly effective on intelligibility, even for students obtaining a low score of 0 points, besides the limitation of the effect on explanation capability of the phenomenon for 0 points score students who on the whole did not tend to be aggressive with the lesson. This result indicates that learning with imaginative thought and behavior is important for students to understand chemical reactions by evaluation.

Imaginative thought and behavior in science is essential for promoting creativity as an outcome with value to the original objective (Wardle, 2009; Finke, Ward, and Smith, 1992; Ohshima, 1920; Fujii and Ogawa, 2011; Ogawa, 2011). Child (2009) and Osborne et al. (2003) have discussed creativity and imagination and have stated that students should appreciate science as an activity that involves creativity and imagination as much as several other human activities.

<table>
<thead>
<tr>
<th>Q</th>
<th>Correct answers/</th>
<th>Pre-</th>
<th>Post-</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>41</td>
<td>83</td>
<td>92</td>
<td>+9</td>
</tr>
<tr>
<td>Q2</td>
<td>45</td>
<td>90</td>
<td>88</td>
<td>-2</td>
</tr>
<tr>
<td>Q3</td>
<td>45</td>
<td>67</td>
<td>82</td>
<td>+15</td>
</tr>
<tr>
<td>Q4</td>
<td>12</td>
<td>82</td>
<td>84</td>
<td>+2</td>
</tr>
<tr>
<td>Q5</td>
<td>8</td>
<td>47</td>
<td>59</td>
<td>+12</td>
</tr>
</tbody>
</table>

*The lesson of the “activated complex,” 49 persons. Questions refer to the structure (Q1), direction of the chemical reaction (Q2), quantity (Q3), reaction rate (Q4), and comparison between catalytic and non-catalytic reactions (Q5). Δ = (post-) – (pre-).
and that some scientific ideas are enormous intellectual achievements. Scientists, as much as other professionals, are passionate and involved humans whose work relies on inspiration and imagination (Osborne et al., 2003). Even in science education, it is more desirable for students to educate themselves in a similar manner.

Visualization is a key for students to have images of objectives, such as phenomena and chemical concepts. The application of visualization to chemical education is one of the significant tools for students to realize science and chemical concepts and phenomena, which has been previously reported, e.g., visualizing chemical structure (Davis et al., 2010), molecules (Tasker and Dalton, 2006), and models and modeling in science (Tversky, 2005; Ogawa, Inoue, and Ikou, 2012; Ogawa et al., 2013). Special emphasis on imagination at an appropriate stage of student activities with drawing and self-explanation in this lesson model would be a methodology influential for enhancing the images of chemical reactions. Realizing images are expected to be enhanced with the hope of creating imaginative thought and behavior. Moreover, imagination would be emphasized with the hope of acquiring sufficient knowledge and skills toward the promotion of creativity. The concept of promoting creativity in science has been raised and discussed for a long time (e.g., Child, 2009; Höhn and Harsh, 2009; Jarvis, 2009; Longshaw, 2009; Ohshima, 1920; Osborne et al., 2003). Imaginative thought and behavior in science promotes creativity as an outcome along with serving a primary pedagogical objective (Finke, Ward, and Smith, 1992; Wardle, 2009). Learning with imaginative thought and behavior is of significance for understanding science. The lesson models discussed in this paper could be applied as a methodology in related future studies.

Acknowledgement

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References


(Received September 30, 2015; Accepted April 12, 2016)
Appendix 1. Self-explanation sheet

| “Activated complex (Energy)” | School reg. #:
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation (Terms in right column available)</td>
<td>M F Name:</td>
</tr>
<tr>
<td>Reaction system/ Product/ Activated/ complex/ Activated state/ Gibbs (free) energy change ($\Delta G$)/ Activation energy($E_a$)/ Chemical equilibrium/ (Equation)/ Chemical reaction/ Reverse reaction/ Equilibrium constant/ Reaction/ Velocity/ Reaction rate constant/ Catalyst/ Binding energy/ Thermo chemical equation/ Conservation of energy/ Hess’s law</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 2. Intelligibility test

<table>
<thead>
<tr>
<th>No.</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1.</td>
<td>Activated complex</td>
</tr>
<tr>
<td>Q2.</td>
<td>Direction of the chemical reaction</td>
</tr>
<tr>
<td>Q3.</td>
<td>Reaction amount</td>
</tr>
<tr>
<td>Q4.</td>
<td>Reaction velocity</td>
</tr>
<tr>
<td>Q5.</td>
<td>As for the feature of a catalytic reaction as compared to a non-catalytic reaction</td>
</tr>
</tbody>
</table>

(Correct answers: 1 or 5 (Q1), 3 (Q2), 1 (Q3), 5 (Q4), and 3 (Q5))