- Invited Workshop 1
- Date: Wednesday, October 26, 2011
- Time: 15:20 ~ 16:20
- Room: #1 (1F)
- Chair: Ki-Young Lee (Kangwon National University, Korea)

CHEMICAL EDUCATION FOR CREATIVITY: KNOWLEDGE, JUDGMENT, AND REPRESENTATION

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1. Introduction

It is important for student to have thinking and behaving imaginatively, and finally to have an outcome which is of value to the original objective [1, 2]. Promoting creativity in science has been reported and discussed in papers [3-8]. Actually, international evaluations of PISA [9] and TIMSS [10] show that Japan places still high level in education concerning about the competence of student. However, they simultaneously demonstrate some weak points of i) poor logical thinking, ii) quite little number of student in excellence, and iii) meager creativity. Special interest of ours is devoted to this school education, especially in chemical education. The lessons still in Japan, even in the world, tend to be usually carried on the way of wiggle behavior of student's listening, writing, and answering including testing through a teacher-centered class-lecture. The lessons, we propose, are favored to proceed under the way of dialogue between students and teacher, and of activities of student himself after the former dialogue. The learning on the basis of students' enthusiastic activities over imaginative thinking and behaving would be of great importance to understand science and chemistry.

Our session entitled "Chemical Education for Creativity" will be expected to provide a platform for participants to share and discuss new ideas, techniques and strategies for promoting creativity in science education, especially chemical education. In this paper, chemical education for creativity would be raised and discussed from the aspects of theory and practice, namely a basic conception of creative thinking (by Ogawa) and a lesson model toward promoting students' creativity (by Fujii).

2. Basic Conception of Creative Thinking

We have proposed a fundamental feature of school lesson in science and chemistry in which a Special Emphasis on Imagination leads to Creation (SEIC) [11]. Having imagination is emphasized with the hope of acquiring sufficient knowledge and skills toward promoting creativity in this SEIC program. Development of the lesson models such as rust of iron and surface-active agent through the principle of SEIC has been reported, and the model was effective for students to realize images of the chemical reaction of rust of iron accompanied by an acquisition of sufficient knowledge [12]. Especially, a way of the lesson through drawings was one of the influential methodologies for enhancing images of the chemical reaction, and students felt some importance comparatively to imagination through experiment & observation and application of schemes as an important item for learning methodologies.

2.1 What is Creativity?

Image and knowledge

First, we thought brain and counterpart outcome mentioned in Fig. 1. These words are enumerated as a similar manner. For example, we thought the image of some animal such as a cow (Fig. 2). Various and independent images to it are floated in the brain. On the counterpart, the letters and words such as cow are considered to be objective image of knowledge. Knowledge of cow is defined specific animal at least and goes to be common. Individual image goes to the image accompanying similarity and common in the progress of level. The high level of image reaches knowledge and a combination of knowledge. Subjective images are converted to objective image with clear definition.

Knowledge as a higher level of image is categorized as like those of three levels as shown in Fig. 3, i.e. the first as concept, the second as descriptive knowledge, and the third level as procedural one. From another standpoint, actual knowledge and potential one are there.

Brain	Outcome
Virtual	Real
Abstraction	Fact
Subjective	Objective
Personal	Impersonal
Images	Operations

Fig. 1 Brain and counterpart outcome

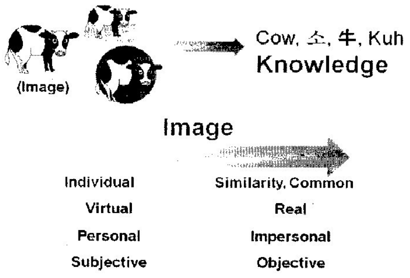


Fig. 2 Image toward knowledge

Knowledge:

i) **Concept**
(ex., "Gas", "Water vapor"),

ii) **Descriptive knowledge**
(ex., "Water vapor is the water on gaseous state"),

iii) **Procedural knowledge**
(ex., "Quantity per unit volume is requested by the dividing calculation")

Actual knowledge (: searchable, in short-term memory)
vs.
Potential knowledge (: search impossible, in long-term memory)

Fig. 3 Knowledge

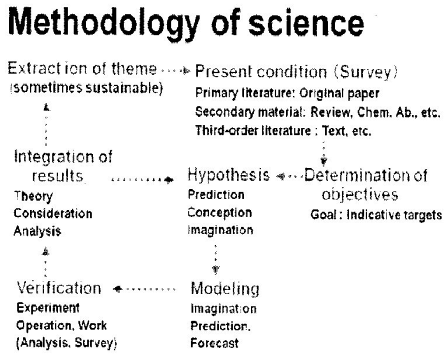


Fig. 4 Methodology of science

Problem-solving as methodology of science

One typical methodology of science represented in Fig. 4. The first, theme of research is extracted and the next, survey of present condition concerning the theme, determination of objective, hypothesis, modeling, verification, and integration of result are subsequently followed. Sometime reaches to be goal of achievement of theme. Normally, some specific steps are repeated from a certain result and sometime prolonged. In all processes imagination plays very important role, particularly in these processes of hypothesis and modeling. Knowledge and skills are also sufficiently exploited in all processes, of course. (Scientists, as much as any other profession, are passionate and involved humans whose work relies on inspiration and imagination as mentioned by Osborne [4].) Even in science education it is more desirable that students should educate themselves in a similar manner.

The process of problem-solving in science education is matched to the methodology of science in which creative thinking by use of knowledge is made good use. It makes a start on information-processing toward problem-solving in the process of creative thinking by use of knowledge. From the standpoint of relationship with knowledge in problem-solving, problem-solving pattern is categorized in three levels where Ⅰ) answer from views using actual knowledge such as "What is the physical quantity appropriate to show heat?", Ⅱ) answer by leverage using actual and potential knowledge such as "Why is calorific value appropriate to show heat?", and Ⅲ) answer by creative thinking requested conception (new ideas) accompanied with the creation of new knowledge structures such as "Which physical quantity is the best candidate to show heat exothermal?" are therein. The higher level becomes the more advanced and creative. Creative thinking has a strong relationship with problem-solving.

Creative thinking toward creation

Creative thinking would be defined two phases, where i) thinking toward creation of new knowledge by the combination of existing knowledge and ii) thinking toward creation of new appropriateness and/or new view to existing knowledge are nominated. These creative thinking are done the backup from interdisciplinary standpoint with four items of i) motive and wills toward creation, ii) aiming power of appropriateness to issues of events, ii)

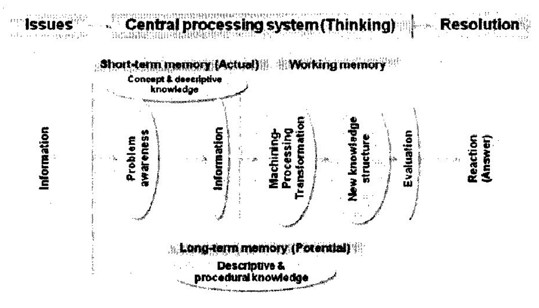
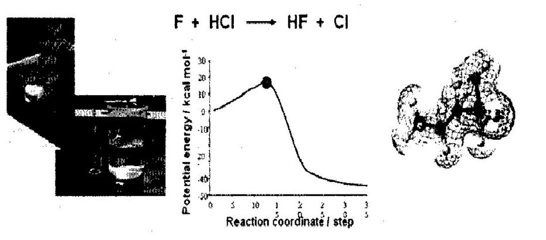


Fig. 5 Information processing scheme



Observable Level ⇔ Symbolic Level ⇔ Molecular Level
(Macro Level ⇔ Symbols & Equations ⇔ Micro Level)

Fig. 6 Dividing the image into the three thinking levels

thinking by operation of knowledge, and iv) power to find out and determine the value. As a whole, we integrate and come out with the information processing scheme as shown in Fig. 5. Zone of pale red color means the inside of the brain. Once some issue comes in the brain, central processing system (thinking) starts to work in the brain, where information enters the brain and fixed as issues reflecting the interactions with concept and descriptive knowledge in short-term memory (actual knowledge) and descriptive and procedural knowledge in long-term memory (Potential knowledge). After that, the issue is subjected to such machining-processing and transformation, and then new knowledge structure is constructed and evaluated. Finally resolution comes out accompanying some reactions. Knowledge based on images works in all processes and plays very important role in the central processing system toward creative thinking lead to creation. Consequently, imagination would boost creativity.

2.2 What is SEIC?

SEIC policy

The learning on the basis of students' enthusiastic activities on imaginative thinking and behaving would be of great importance to understand science. Student's attitude being enthusiastic toward the possibilities of their own abilities with their own images would enhance the understanding of objectives. This approach of SEIC is expected that affluent images can enhance to foster creative thinking led to creativity through making good use of thought, ability for expression, and reason. Having imagination is emphasized with the hope of acquiring sufficient knowledge and skills toward promoting creativity in this SEIC program. The strength of will for imagination and creation will be raised. SEIC has the feature of student-initiative-activities such as brain-storming and student own activity, if need be, with teacher's support. The lesson puts a special emphasis on enhancing the imagination connected with creativity. The lesson proceeds properly by taking advantage of experiment, drawing, and CG based on quantum chemical calculation at appropriate stage of the lesson on the three thinking levels of observable level, symbolic level, and molecular level, respectively (Fig. 6). Dividing the lecture stage into the three thinking levels was mentioned by Tasker *et al* [13]. Visualization as a key of representation of images is great help for student to have images of phenomena, chemical concepts, and molecular world, and then the visualization enables student to realize images of them. Students' enthusiastic activities with imaginative thinking and behaving are expected in this SEIC program.

Lesson models

Fifteen themes were selected for the lessons in chemistry (for teaching profession in primary school) to an undergraduate university student. Fundamental contents on the topics were chosen on the basis of basic chemistry; i.e. the chemistry is roughly composed of three frames of structure, equilibrium, and change. Fifteen lessons in the model covered them moderately. Above all, three lessons from lesson 4 to lesson 6 include fundamental concepts in chemistry, i.e. stoichiometry, free energy, and entropy from the standpoint of rust of iron. The lessons proceed toward the theme of topics, i.e., the lesson 4, 5, and 6 proceed toward the themes of stoichiometry, activating complex, and entropy change of chemical reaction of rust of iron, respectively.

The lesson is typically divided in five activities. For example as 90-minute lesson, even in a lecture in about 45 minutes frequent discussions is performed with no students' memorization, and afterwards students' own memorization and collection of their thoughts in 10 minutes are carried out. Students' activities of drawings toward making images of chemical concepts and phenomena, and self-explanation should be performed in 15 and 10 minutes, respectively.

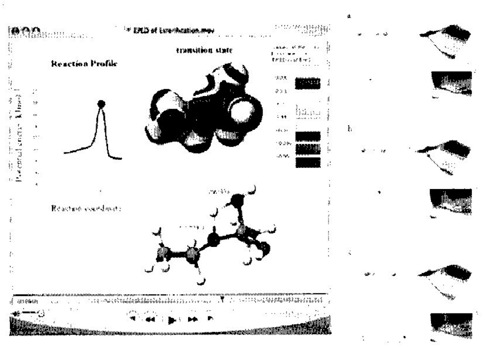


Fig. Esterification (AcOH + EtOH · AcOEt + H2O) Fig. Composition of CGs

Fig. 7 CG graphics

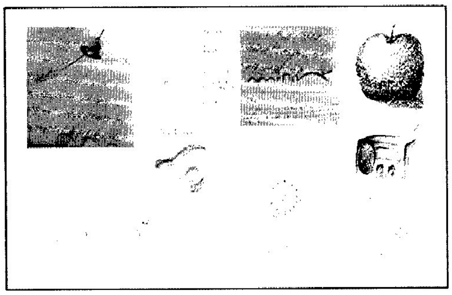


Fig. 8 Being but unseen (Lesson 1)

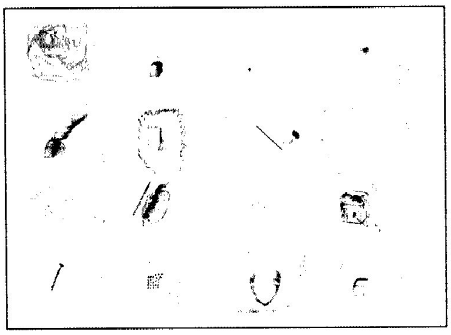


Fig. 9 Entropy: exothermic: rust of iron (Lesson 6)

Visualization toward images

Visualization is a key for student to have images of phenomena, chemical concepts, and molecular world, in which drawing, experiment, and CG based on quantum chemical calculation are taken advantage of properly at appropriate stage of the lesson on the three thinking levels of observable level, symbolic level, and molecular level, respectively. Realizing images led to understanding are expected to be enhanced with the hope of students' enthusiastic activities on imaginative thinking and behaving. CG graphic as a teaching material (Fig. 7) and students' drawings in the lesson (Fig. 8, 9) are raised as an example. Drawing is imposed on the students in the lesson as one of chief activity, where drawing rules are set as following; drawings should be attractive for everybody to see once again. Prohibition on drawing is regulated, e.g., description of text, mark, line, arrow, and illustration with simile in a drawing area. Explanations by text style were also available outside the drawing area in a sheet using chemical terms by solid-parting line.

2.3 Discussion

Scientists, as much as any other profession, are passionate and involved humans whose work relies on inspiration and imagination as mentioned by Osborne [4]. Even in science education it is more desirable that students should educate themselves in a similar manner. Thinking and behaving imaginatively in science would be important to promote creativity as outcome with value to the original objective [1, 2, 8, 14]. Child and/or Osborne, *et al.* mentioned that students should appreciate that science is an activity that involves creativity and imagination as much as many other human activities, and that some scientific ideas are enormous intellectual achievements [3, 4]. Visualization is a key for students to have images of objectives as in phenomena, chemical concepts, and molecular world. Students will have the images of the three thinking levels of observable level, symbolic level, and molecular level. Visualization at an appropriate stage of Experiment, drawing, Explanation, and CG based molecular world on quantum chemical calculation would be effective methods for those achievement. Realizing images led to understanding are expected to be enhanced with the hope of students' enthusiastic activities on imaginative thinking and behaving. Having imagination would be moreover emphasized with the hope of acquiring sufficient knowledge and skills toward promoting creativity. The learning on the basis of students' enthusiastic activities on imaginative thinking and behaving would be of great importance to understand science on the three thinking levels. Student's attitude being enthusiastic toward the possibilities of their own abilities with their own images would enhance the understanding of objectives. A further development of teaching materials is sincerely expected.

3. Lesson Model Toward Promoting Students' Creativity

The promotion of students' creativity is one of the recent research concerns in science education. For instance, School Science Review, a main magazine of Britain, made a special issue: "Creativity in Science" in 2009 [1, 5, 6, 7 and etc.]. Moreover, Revised Course of Study of high school science in Japan was announced in 2009, where the new subject of "Research Project of Science" was established in order to cultivate a base of students' creativity [15]. However, the research of this field in the high school chemistry develops up to now, and therefore neither proper contents of lesson nor effective teaching and learning methods to the promotion of creativity is shown.

On the other hand, the iron as the topic of this study is an important material widespread to our life. Many of machines, buildings, and living goods are made of iron. And then, a large amount of natural resources and energy such as iron ore, coal, water and etc. are needed for the production of iron. Therefore, we can understand the utilization of materials in today's life and society by paying attention to iron and consider a direction of the development and the utilization of materials in the future.

A lesson model of high school chemistry on the topic of iron is proposed herein, which is aimed at promoting student's creativity. An assumption which would influence the acquired knowledge and the judgment ability concerning feature of iron toward the creativity related to utilizations of iron is examined through this study.

3.1 Development of Lesson Model

The aim of making a lesson model is to promote the student's creativity based on knowledge and judgment ability concerning feature of iron. Contents of the lesson are composed of the following items:

- Lecture (120 min.): "Iron: raw material, manufacturing, utilization, and the history";
- Experiment (120 min.): "Metal plating on iron sheet and corrosion-protection by plating on iron sheet";
- Study Tour (half day): "Steelworks";
- Activity (180 min.): "Gathering information of iron and other materials for automobile by the Internet web sites", "Evaluation about utilization of iron and other materials for automobile."

A manual for the lecture, work-sheets for the experiment, and evaluation-sheets for the activity were made and exploited.

3.2 Trial of Lesson Model

The lesson model was carried out with 36 Japanese students (Hiroshima University High School) and 30 Korean students (Cheonan Jungang High School) of the 11th grade during two days on January 12th through 13th, 2011. The 22 science questions selected from TIMSS were conducted with the students before the lesson in advance. When the score rate average of Japanese and Korean students was calculated, t-test was given to the average with p-value of 0.165 point ($p>0.1$). There was not necessarily significant difference in the academic achievement among both of students. Therefore, the students were of a proper research object for the approval of this comparative study.

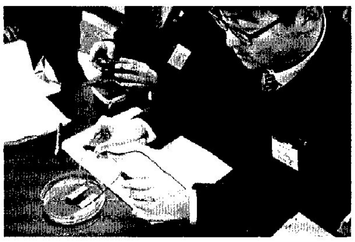


Fig. 10 Metal (Tin, Zinc and Nickel) plating on iron sheet

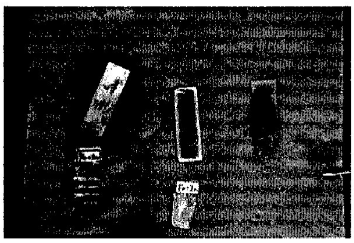


Fig. 11 Corrosion protection of plated iron

The first day; lecture and study tour in the lesson were carried out. First of all, the lecture on "What kinds of materials is an automobile made from" was performed in order to attract students' interest on the topic of iron. Then the lecture about (1) raw material of iron, (2) manufacturing of iron: the actual manufacturing process and that regarding to saving of energy and reducing of carbon dioxide, (3) utilization of iron: type of use, alloy, protection against corrosion, and recycling of iron, and (4) history of iron. In a part of the content (2), reduction of iron oxide with hydrogen instead of coke was demonstrated as a teacher experiment. In the study tour, a steelworks in the suburb of Hiroshima city was inspected and information about iron was gathered.

The second day; experiment and activity in the lesson were conducted. The experiment of the metal plating (tin, zinc and nickel) on iron sheet was done (Fig. 10). Then the corrosion- protection by plating on iron sheet was tested with potassium ferrocyanide solution by comparing color changes under the conditions of scratching with the tip of a nail and dropping sodium chloride solution (Fig. 11). In the activity, information about iron and other materials for automobile components was collected by Internet web sites. Then possibilities of utilization of iron and other materials were discussed as a group activity, and then models of future automobile made from prospective materials were creatively sketched as an individual activity.

3.3 Evaluation of Lesson Model

In the case of related terms of iron enumerated by the students, the knowledge about physical properties of iron remarkably increased in number among both of the students after the lesson. The number per a student was about 1.9 times large in Japanese students and 2.5 times many in Korean students. The knowledge was those referred to as connecting category of knowledge and forming networks of knowledge (Fig. 12).

Regarding the assessed materials (steel, aluminum alloy, and synthetic resin) from the standpoint of utilization for the body of automobile, about 43% and 32% of assessment criteria enumerated by Japanese students and Korean students, respectively, were those related to physical property of materials (specific gravity, strength, hardness, durability, and forming, etc.) (Question 1 in Fig. 13) [16]. Then performance value of the assessment which were allocated by the students displayed their judgment based on acquired knowledge concerning physical properties and other features (price and recycling, etc.) of materials (Question 3 in Fig. 13).

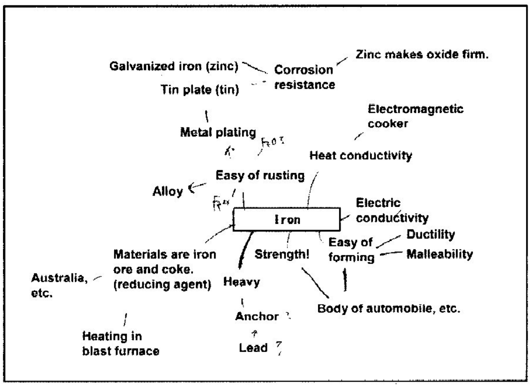


Fig. 12 Acquisition of knowledge about physical properties of iron (after the lesson)

1 Assessment of Material

Carry out your own assessment of the three materials (steel, aluminum alloy, and synthetic resin) in the aspect of the utilization for automobile's body.

1) Write down ten criteria which are important for your assessment of three kinds of materials (steel, aluminum alloy, and synthetic resin), in individual work.

2) Select five of the ten criteria which you want to use for the assessment, in group work.

- cost
- strength
- recycling
- easy to make
- weight

3) Assessment of the material steel:

List your selection of criteria and determine the importance factor of each criterion by allocating a total 20 points to the five criteria.

Assess steel after each criterion and allocate the performance value to it (5 = very good to 1 = inadequate).

Calculate the total value by multiplying the performance value of the respective criterion with the importance factor. Then add the single total value. In order to calculate the final grade, divide the sum of the total value by 20.

Steel			
Criterion	Importance factor	Performance value	Total value
A price/cost	5	4	20
B strength	7	4	28
C recycle	2	3	6
D easy to manufacture	4	4	16
E weight	2	1	2
Sum	20		72
			:20
Final grade			3.6

Write the reason why your group determines the importance factor and the performance value to each selected criterion.

Fig. 13 Work-sheet to assess materials of automobile (Omission about assessment of aluminum alloy and synthetic resin in Question 3))

In the case of selected materials used for some parts of future automobile with rough sketch, some students showed creative representations including originality, practicality, sensibility, and/or inclusiveness [2 on p.37-43]. These representations were based on the judgment to the value of materials from the points of features including physical property while the representations were or not those reflected knowledge about materials (Fig. 14: a creative representation including originality. In the student's assessment of materials, final grade of synthetic resin is higher as well as that of steel.).

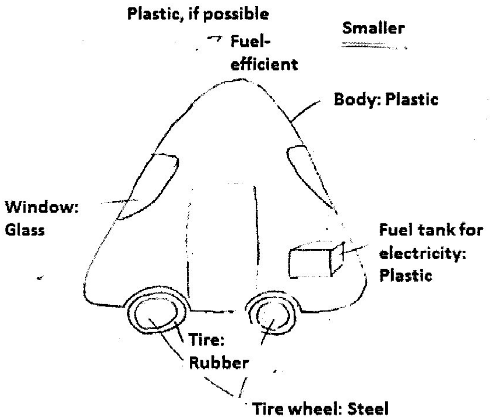


Fig. 14 Materials of some parts of future automobile

3.4 Closing

According to Finke *et al.* [2 on p.89], the restriction of imagination on the task, which is given to objective person, is an important factor for promoting their creativity. This was supported by the result of this study. Indeed, the students who clearly understood the restriction on the task of "future automobile" imaged solar car, electric vehicle, or fuel-cell car, and selected suitable materials for these automobiles. Then the students who focused on body and frame along another restriction on the task of "parts of automobile" deeply considered materials of the parts. Our further research would be to investigate setting of the task for promoting students' creativity. Moreover, a significant relation between students' creativity and judgment ability related to features of materials including iron was found by this study while the relation between students' creativity and acquired knowledge was not made clear through the survey in this time. Some modify of the survey would be needed in the further research.

References

[1] Wardle J. (2009). Creativity in science, School Science Review, 90 (332), 29-30.
[2] Finke R. A., Ward T. B., and Smith S. M. (1992). Creative Cognition: Theory, Research and Applications, The MIT Press.
[3] Child E. P. (2009). Improving chemical education: turning research into effective practice, Chem. Educ. Res. Pract., 10, 189-203.
[4] Osborne J., Ratcliffe M., Bartholomew H., Collins S., Millar R. and Duschi R. (2003). Towards evidence-based practice in science education 3: teaching pupils 'Ideas-about-science', available at http://www.tlrp.org/pub/documents/no3_miller.pdf, accessed 2010/10/15.
[5] Jarvis T. (2009). Promoting creative science cross-curricular work through as in-service programme, School Science Review, 90 (332), 39-46.
[6] H?hn L. and Harsh G. (2009). Indigo and creativity: a cross-curricular approach linking art and chemistry, School Science Review, 90 (332), 73-81.
[7] Longshaw S. (2009). Creativity in science teaching, School Science Review, 90 (332), 91-94.
[8] Ohshima T. (1920). Rika Kyoujyu no Genri (Principle of science teaching), Doubunkan Co., 314-330. (in Japanese).
[9] OECD (2004). Learning for Tomorrow's World - First Result from PISA 2003, OECD, 2004.
[10] TIMSS (2003). The Third Intern. Mathematics and Science Study (TIMSS).
[11] Ogawa H., Fujii H., and Sumida M. (2009). Development of a lesson model in chemistry through "Special Emphasis on Imagination leading to Creation" (SEIC), The Chemical Education Journal, 13(1), Registration No.13-1, 6 pages.
[12] Ogawa H. and Fujii H. A Trial of Plantation and Embodiment of Images for Chemical Concepts in the Lesson Model of "Surface Active Agent" through SEIC, Proc. of Intern. Conf. Chem. Educ. 2010 (Taiwan), in press.
[13] Tasker R. and Dalton R. (2010). Visualizing the Molecular World-Design, Evaluation, and Use of Animation, Chapter 6, In Gilbert J. K., Reiner M., and Nakhleh M. (Eds.), Visualization: Theory and Practice in Science Education, Springer, 105.
[14] Domin S. D. (2008). Using an advance organizer to facilitate change in students' conceptualization of the role of creativity in science, Chem. Educ. Res. Pract., 9, 291-300.
[15] Ministry of Education, Culture, Sports, Science & Technology in Japan (2009). Course of Study of High School Science.
[16] Fujii H., Ogawa H., Utsumi R., and Hiramatsu A. (2009). Promotion of Student's Abilities in Proper Judgment on the Topic of Bio-energy: Development of Lesson Model in Chemical Education, The Chemical Education Journal, 13(1), Registration No.13-8, 6 pages.