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Research Article

An Analysis of High School Students' Learning Ability of Modelling about the Topic of Voltaic Cell

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Abstract

Modeling is a model-based learning process, which is repeated through formation, use, modification and elaboration. It is one of the significant factors influencing classroom teaching effect and students' learning results. The paper-pencil test and interview were used to study the modeling ability of 91 senior high school students in xi 'an middle School of Shaanxi province, China. The research results of students' modeling ability showed that: (1) students' modeling ability is generally low. The ability level of each modeling process is relatively low. Only the model construction ability can reach level 3, and the model selection ability, model validity ability and model application ability can only reach level 2. The model deployment ability can only reach level 1. (2) Students paper-pencil test scores and average modeling ability on voltaic cell theme were significantly correlated with each modeling ability (**p<0.01). The students with high modeling ability usually had good academic performance. Judging from the relationship among the five modeling abilities, selection ability was basis of construction ability, validity ability, application ability. However, there is no correlation between the selection and deployment ability, which suggesting that if students cannot understand the limitation and application range of the voltaic cell, they cannot effectively optimize and improve its existing model. (3) The modeling process of students have the characteristics of interpreting by a single factor. It is difficult for students to fully explain the reasons from the connection and extension relationship between factors and the overall structure.

Keywords

Model • Modelling • Modelling Ability • Voltaic Cell

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Modeling is a model-based learning process, which is repeated through formation, use, modification and elaboration. (Buckley & Boulter, 2000). The modeling ability is to describe students' ability level in the process of modeling. Modeling ability is an indispensable ability for students development in science education (Chiu, 2008), and an important way for students to understand the world. Developing students' modeling ability is an important goal of science education. Justi, van Driel (2005) indicated that the model and modeling in science and education has three parts: the first part is learning science. Students should understand the major scientific model and the scope and limitations of the model (Gilbert & Boulter, 1998; Justi & Gilbert, 2003); the second part is doing science. Students should have opportunities to create, express and test their models (Greca & Moreira, 2000; Harrison & Treagust, 2000; Justi & Gilbert, 2003); the last part is learning the nature of science. Students should learn the nature of model and understand the role of model (Justi & Gilbert, 2002). However, "science modeling" is the key process to achieve these goals. Nicolaou, & Constantinou (2014) systematically reviewed the empirical research literature of modeling ability assessment, and the results showed that: (1) there is no overall theoretical framework for modeling ability assessment in the existing literature; (2) modeling ability assessment methods are often related to specific areas of competence; (3) evaluation tends to focus on the "meta-" aspect of modeling ability; (4) lack of methods to evaluate some aspects of modeling and the generation process of modeling; (5) a more clear and coherent theoretical framework for conceptualizing modeling abilities is needed. They divided modeling ability into five dimensions: (1) modeling practices; (2) meta-cognitive knowledge about the modeling process; (3) meta-modeling knowledge; (4) the modeling product (models); (5) the modeling product (models) which is the cognitive process of modeling and the theoretical framework of modeling capability assessment has been developed.

Greca & Moreira (2000) believe that the process of modeling has been understood by most people in three ways: Firstly, consider modeling as "sequential learning steps," selecting or using models according to obvious rules; Secondly, think of modeling as "learning a new language", providing another idea for the description of phenomena; Lastly, modeling is regarded as an "integrative reasoning process", which is combined with simulation, visualization, thinking experiments and other methods to further create and transform the representation of daily problems. Therefore, the process of modeling is sequential and belongs to a special platform. Combining with the integrative reasoning process, students' daily mental models are transformed into scientific models, which will lead to meaningful learning. Grosslight (1991) first researched modeling ability level and divided it into level 1-3 according to students' understanding of model. Level 1: there is a one to one corresponding relationship between model and entity and model is a smaller, correct reproduction of real things. Students will not find models' form and purpose. Level 2: this level focuses on the key elements of entity. Model is still a real world object or event rather than the idea of representation and model is used as a tool of communication, not to explore ideas. Level 3: the model is used for development and testing. It is an abstract idea, not a description of an entity. And models are multiple, thinking tools, and focus on the ability of explaining and predicting.

Halloun (1996) represented the scientific model construction as five steps: model selection, model construction, model validity, model analysis and model deployment. Chang & Chiu (2009) summarized the modeling ability on the basis of Halloun (1996) into six continuous construction processes: model selection, model construction, model validity, model application, model deployment and model reconstruction.

According to previous research, Chamizo (2013) defined the specific connotation and classification of models, and the learning of model understanding as a tool for prediction and interpretation is divided into four levels: (1) the students can't learn knowledge by model, but model can be used to represent the knowledge; (2) students can explain how phenomena arise by constructing and using models, which can be consistent with the phenomenon shown. (3) as for the existing problems and new phenomena, students can use models as tools to support their own thinking. Students can analyze the advantages and disadvantages of alternative models and explain and predict the construction process of these models. (4) students can spontaneously construct models of different fields to illustrate their own thinking and understanding.

The research of modeling ability has its theoretical framework, but the operation of thematic knowledge is not strong. The topic of electrochemistry is the key and difficult point of chemistry teaching in high school, and there are many misconceptions for students. Garnett & Treagust (1992) used semi-structured interview to study Australian high school students' misconceptions about electrochemistry. The study found that the students' misconceptions mainly focused on the following aspects: (1) misjudging the electrode polarity of voltaic cell and electrolytic cell; (2) the electrode is charged; (3) the movement of charge in electrolyte solution is unclear; (4) not understanding the effect of standard electrode potential; (5) the electrode products cannot be accurately determined. Sanger & Greenbowe (1997) increased concentration cell based on the study of Garnett and Treagust and restudied taking American students in introductory chemistry courses as a new sample. In addition to the conclusions similar to those of Garnett and Treagust, there are also some other misconceptions about the electrode potential. Some students believe that the electrode potential is independent and can predict whether the electrode reaction will occur or not.

In this study, the theme of voltaic cell was selected as the research object, and the existing evaluation model of modeling ability was used to detect the modeling ability level of Chinese high school students.

Research design

Purpose

The main purpose of this study is to measure the modeling level and the specific process of Chinese students in the theme of voltaic cell based on the division of modeling ability index and modeling ability level. The three main research objectives are as follows:

1. Probing students' modeling ability in the theme of voltaic cell based on evaluation index about modeling ability by Chang & Chiu (2009);

2. Understanding students' the specific modeling process when learning voltaic cell by semi-structured interview.

3. Analyzing the difference and relationship between test scores and modeling ability for the students on different levels to find out the reasons of low level modeling ability and providing the corresponding teaching suggestion.

Subject

A sample of 91 senior one students from xi 'an middle school in Shaanxi province, China whose academic level is higher than average level were selected as subjects. According to the paper-pencil test results, 30 students from high, middle and low levels were randomly selected to conduct in-depth interviews.

Method

In this study, the paper-pencil test and interview were used to study the students' modeling ability in the theme of voltaic cell. The questionnaire about voltaic cell included 11 open questions, of which question 1-2 surveyed students model selection ability; question 3-5 for model construction ability; question 6-7 for model validity ability; question 8-9 for model application ability; question 10-11 test questions for model deployment ability. Interview is adopted to analyze specific modeling process of the voltaic cell theme. The researchers counted and coded the test questions and ranked the standard coding scores according to the designed level of modeling ability on the theme of the voltaic cell. Using SPSS2.1.0 statistical software to analyze the data.

Description of the evaluation standard of the modelling ability level on voltaic cell

Table 1
Modelling Process and its Connotation

modeling process	Main content	Key pointt
model selection	The student will automatically choose a model from his mind that can solve the problem when faced with a particular problem. That is, the student will choose an appropriate one to solve the problem from a familiar model.	Achieve the goal first, and work with the model chosen by personal experience to solve the problem.
model construction	After perceiving the problem, students begin to build model diagrams, confirm the relevant components and structures of the selected model in the first step, generate scientific hypotheses, and represent specific models.	Establish a preliminary model of personal problem solving to solve the problem at hand.
model validity	After establishing the initial model for solving the problem, students need to start the experimental stage, and test the internal consistency of the initial model by various ways to judge whether the model needs to be modified or not.	Considering the applicability of each quantified element in the preliminary model, the individual model is partially modified.
model application	After correcting the model, students can use the validated model to find the solution to the problem and interpret the problem in similar situations, or to judge the suitability of the solution.	Focus on the problem that been interpreted, establish evidence, and verify the relevance of the model.
model deployment	If the model applied by individuals is adaptable, students will use this model to solve problems in various new situations, design and conduct empirical tests to evaluate the applicability of this model.	Test the serviceable range and new situation of this mode.
model reconstruction	If the model applied by individuals cannot be used to make inferences about similar problem situations, students will perceive the limitations of the model and then develop more explanatory models.	Examine each step to make sure if any improvements are needed.

Note. Since the subjects of this research are senior one students, and their knowledge system of voltaic cell is not comprehensive enough, this study only evaluates students' modeling ability level and modeling process in the first five steps.

According to modeling process (Halloun, 1996) and analytical framework of modeling index (Chiu, 2007; Chang & Mei-Hung Chiu, 2009), this research divides modeling process into six steps (table 1): model selection, model construction, model validity, model application, model deployment and model reconstruction.

Based on the modeling ability division level (Chang & Chiu, 2009), modeling ability level could be divided into experience response, single factor, multiple factors, relationship level, extend relationship level and scientific theory according to the quality and complexity of the model structure, which is related to the modeling ability Level 0 ~ 5 in the theme of voltaic cell (Table 2).

Table 2
Division Standard of Modelling Ability

Evaluation criterion	Corresponding ability level	Main content
experience response	Level 0	Facing with a specific problem that cannot be experienced, students begin to speak incoherently and answer ideas that have nothing to do with the problem situation.
single factor	Level 1	When a specific question is applied to relevant scientific and theoretical knowledge, students will introspect their own experience and answer questions according to prior experience.
multiple factors	Level 2	Students can answer more than two theoretical factors to a particular question.
Relationship level	Level 3	When using multiple relevant knowledge of a known theory to analyze a certain problem, students will link the multiple knowledge to the problem, and then construct the concept of relationship level to answer questions through reflection or re-learning.
extend relationship level	Level 4	Facing with a problem, students can further extend and abstract the concepts between multiple factors.

In terms of the knowledge of voltaic cell, voltaic cell is a device that converts chemical energy into electrical energy from the perspective of energy conversion. From the point of chemical reaction, the principle of the voltaic cell is that the electrons from reducing agent is transferred to the oxidizing agent through an external wire in the redox reaction, so that the redox reaction takes place on two electrodes respectively. Voltaic cell must meet four basic conditions: electrodes with different activity, electrolyte solution, spontaneous redox reaction and closed circuit. Therefore, in the process of constructing the model, in addition to the difficulty of students in answering the ideas related to the problem situation, the four basic conditions correspond to the single factor, multiple factors, relationship level and extended relationship level

Therefore, except for experience response that student cannot answer the ideas about problem situation, single factor, multiple factors, relationship level and extending relationship level which based on the four conditions in the process of modeling are shown in table 3:

Table 3
Modelling Ability Level Division Standard About Voltaic Cell

Constitute conditions	single/multiple factors	relationship level	extend relationship level
one	electrodes with different activity	electrode + electrolyte (internal circuit)	electrode + electrolyte, electrode + redox reaction extending to the direction of ions movement
two	electrolyte solution	electrode + redox reaction	electrode + electrolyte, electrolyte + redox reaction extending to electrode reaction equation
three	spontaneous redox reaction	electrolyte + redox reaction	electrode + redox reaction, electrolyte + redox reaction extending to the overall reaction equation
four	closed circuit (wire)	electrode + external circuit (wire)	electrode + redox reaction, electrode + external circuit (wire) extending to the direction of electrons movement

Table 4
Modelling process evaluation criteria about voltaic cell

modeling process	Level 1	Level 2	Level 3	Level 4
model selection	Answer one constitute condition and 0-1 microscopic concepts about constitute conditions.	Answer 2-4 constitute conditions and 0-4 microscopic concepts about constitute conditions.	Answer 3-4 constitute conditions and 0-4 relationships.	Answer 3-4 constitute condition, 2-4 relationships and 0-4 extending relationships.
model construction	Draw the diagram about one constitute condition and answer 0-1 microscopic concept about constitute conditions.	Draw the basic structure of electrode-electrolyte-wire-closed loop and mark the name of 0-4 materials.	Draw the basic structure of electrode-electrolyte-wire-closed loop-light bulb, mark their name and point out 0-4 relationship layers.	Draw the basic structure of electrode-electrolyte-wire-closed loop- light bulb, mark their name and point out 3-4 relationship layers; Mark the 0-2 directions of ions or electrons movement and 0-3 reaction equations about cathode, anode or redox reaction.
model validity	Point out one constitute condition of the voltaic cell and 0-4 factors (physical, chemical) that affect battery performance.	Point out 2-4 constitute condition of the voltaic cell , 0-2 factors (physical, chemical) about constitute condition that affect battery performance and inspection methods about battery.	Point out 3-4 constitute conditions of the voltaic cell, 0-2 factors (physical, chemical) about constitute condition that affect battery performance and how it affect battery performance. Point out inspection methods about battery and its' conclusion.	Point out 3-4 constitute conditions of the voltaic cell, 0-2 factors (physical, chemical) about constitute condition that affect battery performance and how it affect battery performance. Point out inspection methods about battery and its' conclusion and reasons.
model application	Explain the differences and similarities between the two constitutive materials from one constitutive condition of voltaic cell; Point out 0-1 difference and one limitation factor about a fruit battery.	Explain the differences and similarities between the two constitutive materials from two constitutive conditions of voltaic cell; Point out 1-2 specific difference and two limitation factors about a fruit battery.	Explain the differences and similarities between the two constitutive materials from three constitutive conditions of voltaic cell; Point out 2-3 specific differences and three limitation factors about a fruit battery and state the reasons.	Explain the differences and similarities between the two constitutive materials from 4 constitutive conditions of voltaic cell; Point out 3-4 specific differences and four limitation factors about a fruit battery and state the reasons and point out 0-4 improved methods.
model deployment	Explains how to make a homemade battery more voltage/longer life based on one constitute condition of voltaic cell and point out 0-1 reason.	Explains how to make a homemade battery more voltage/longer life based on two constitute condition of voltaic cell and point out 1-2 reasons.	Explains how to make a homemade battery more voltage/longer life based on three constitute condition of voltaic cell and point out 2-3 reasons.	Explains how to make a homemade battery more voltage/longer life based on four constitute condition of voltaic cell and point out 3-4 reasons.

The single factor in table 3 refers to the ability to answer one of the four basic conditions that make up the voltaic cell, such as electrolyte solution. Multiple factors refer to the ability to answer 2-4 conditions from the four basic conditions. For example, two electrodes of copper sheet and zinc sheet are used to make the voltaic cell. Copper sheet and zinc sheet connected by a wire are inserted into dilute sulfuric acid. A closed circuit is formed to form the voltaic cell. Since the basic conditions that make up the voltaic cell are the same, they are explained together. The relationship level refers to the relationship between the two conditions. For example, the reaction of the anode zinc sheet and the electrolyte dilute sulfuric acid belongs to the relationship between electrode and electrolyte. Extending relationship level is that being clear about the connection between the two-relationship layer of four relationship layer. For example, the fact that anion moves toward the anode and cation moves toward cathode in electrolyte solution belongs to extension relationship between the relationship of electrode and electrolyte and that of electrode and redox reaction. Based on six kinds of modeling ability levels and six types of modeling processes (Chiu, 2007), evaluation criteria about modeling process are established shown as table 4.

Supplementary note: students in level 0 are not able to answer anything related to the modeling process, so level 0 is not included in the table.

Test coding and scoring

According to the analytic coding table (Chang & Chiu, 2009), the questionnaire was encoded based on the analysis of the answers (table 5).

Table 5
The Coding and Scoring of the Questionnaire

Level	coding	scoring
Level 0	0	0
Level 1	1.1.0-1.1.1	Score = (the number of macroscopic factors + the number of microscopic concept)/8
Level 2	2.2.0-2.4.4	Score = 1 + (the number of macroscopic factors + the number of microscopic concept)/8
Level 3	3.2.1-3.4.4	Score = 2 + (the number of macroscopic factors + the number of microscopic concept)/8
Level 4	4.3.2.1-4.4.4.4	Score = 3 + (the number of macroscopic factors + the number of microscopic concept)/8

The answer of the second question in the voltaic cell questionnaire is taken as an example (table 6).

Table 6
The Coding and Scoring Example About the Modelling Ability on Voltaic Cell

	answer	coding	scoring	level
Student 1	Cathode: Carbon rods, copper, PbO_2, etc; anode: zinc, lead, etc; electrolyte: sulfuric acid, etc.	2.2.2	1.5	level 2
Student 2	Wire, acidic fruit, copper coins, steel coins, small bulb, ammeter	2.4.4	2	level 2
Student 3	Wire, switch, sensitive galvanometer, the small bulb, electrolyte solution that can react with at least one of the two conductive materials, such as iron and sulfuric acid	3.4.1	2.625	level 3
Student 4	Wire, electrolyte solution, graphite electrode, hydrogen and oxygen, the movement of ions in electrolyte solution and electronic in external directional form a closed loop; Anode reaction: $2H_2 + 4OH^- - 4e^- = 4H_2O$; Cathode reaction: $O_2 + 2H_2O + 4e^- = 4OH^-$: Overall reaction: $2H_2+O_2=2H_2O$	4.4.3.2	3.75	level 4

The analysis of modelling ability level about voltaic cell

Distribution of modelling ability level about voltaic cell

Calculating the modeling ability level distribution of voltaic cell about 91 students to analyze their model selection ability, model construction ability, model validity ability, model application ability and model deployment ability, shown as table 7.

Table 7 shows that among the modeling abilities in the theme of voltaic cell, there are 79.1% students at level 2 for selection ability and the number of others level is less, which shows that most students can point out the four basic conditions of voltaic cell and explain the reasons for choosing the material. However, insufficient knowledge structure appeared when further explaining the constitute conditions of voltaic cell from the perspective of relationship level and extending relationship level.

Table 7
Students' Modelling Ability Level Distribution About Voltaic Cell (N=91)

	Level 0		Level 1		Level 2		Level 3		Level 4	
	N	percent	N	percent	N	percent	N	percent	N	percent
Selection ability	2	2.2	6	6.6	72	79.1	9	9.9	2	2.2
construction ability	5	5.5	3	3.3	22	24.2	21	23.1	40	44.0
validity ability	8	8.8	25	27.5	51	56.0	7	7.7	0	0
application ability	19	20.9	19	20.9	33	36.3	14	15.4	6	6.6
deployment ability	32	38.5	41	45.1	17	18.7	1	1.1	0	0

There are few students at level 0 and level 1 for model construction ability. There are 24.2% students at level 2, which means that almost a quarter of students can draw the basic structure about electrode-electrolyte-wire-closed loop of voltaic cell, mark the name of each part and correctly assemble voltaic cell device. There are 23.1% students, who can further connect each part of voltaic cell and elaborate their relationship on the basis of level 2, reaching the level 3. From the data, 44.0% students can extend the relationship level to extending relationship level, which mainly reflects on the fact that students can point out the electrode reaction of voltaic cell and know the direction of electron movement at external circuit and ions movement at internal circuit. It is closely related to teachers' teaching—focusing on electrode equation writing and the introduction of working principle of voltaic cell and it's why there are 44.0% students reaching level 4 for modeling construction ability.

As for model validity, 27.5% of the students are at level 1, indicating that about a quarter of them could only recognize the efficiency of the voltaic cell from a single factor. However, 56.0% of the students reach level 2 who can explain the efficiency of the voltaic cell from multiple factors and point out the test method of assembling the battery. Only 7.7 percent of the students reach level 3, and they are able to explain how multiple factors affected the efficiency of the voltaic cell and point out the test methods and conclusions of assembling battery. No student can reach level 4, and the data fully shows that students can superficially know which factors can affect the efficiency of the voltaic cell, but it is difficult to explain the reason and how to influence it. Students rarely analyze and reason from the composition conditions and working principles of the voltaic cell.

Surprisingly, as for model application ability, 20.9% of the students were unable to compare the differences and relationship between homemade batteries and fruit batteries on materials. Not even one of them could be mentioned, indicating that these students could not make further transfer of the voltaic cell composition conditions under new situation. Similarly, 20.9% students who are able to talk about their similarities and differences on only one constituent condition reached the level 1. 36.3% students, reaching level 2, are able to point out 2-3 similarities and differences between the two batteries, and could point out 2-3 restrictions of fruit battery. 15.4% reach level 3. Only 7.7% students are able to explain the similarities and differences from the electrodes, electrolytes, spontaneous redox reactions and closed circuits, and point out the limitations of the fruit battery from its composition. The data of model application ability shows that students lack the understanding of the voltaic cell from the whole setup.

As for the model deployment ability, 38.5% students could not draw the setup with greater voltage and longer life. The reason why students have no way to start was that most of the students could not realize the limitation of homemade battery at the level of model application ability. 45.1% students, reaching level 1, can draw a new device similar to the battery in the textbook based on a single component condition. 18.7% students were able to improve their homemade batteries from multiple factors. However, it is a pity that only 1.1% of students reach level 3, and no students can reach level 4. The reason is that teachers and students pay more attention to the electrode reaction and working principle of the voltaic cell represented by chemical symbols in the process of teaching and learning.

In summary, students' modeling ability is relatively low, and only students with higher modeling ability can reach level 4. The rest of the modeling abilities are at a low Level, especially the validity ability and deployment ability. No students can reach level 4, and few students reach level 3. In terms of the distribution of students, the selection ability is normally distributed, while the construction ability is concentrated on the high level. The validity ability, application ability and deployment ability are all distributed in a skewed distribution with few high-level people. This is consistent with the research results of Chang & Chiu (2009). In the performance of each modeling ability, only the model selection ability and construction ability reach level 3 or above. None of the other modeling capabilities reach level 3 or even level 2. In terms of the population distribution trend, only the model selection ability presents a normal distribution. The model construction ability presents an average distribution, and the rest modeling ability shows a normal distribution (the number of people at the lower level is the majority). Therefore, for the voltaic cell theme, students' modeling ability focuses on how to improve their relationship level and extension relationship level.

Analysis on modelling ability of voltaic cell

Averaging 91 students' five modeling ability level to get their respective modeling ability level, and averaging all students' modeling ability to get their average modeling ability level. The results are shown in table 8.

Table 8
Average of Students' Each Modelling Ability of Voltaic cell(N=91)

	Level 1	Level 2	Level 3	Level 4	mean	modeling ability
selection ability	0.58	1.47	2.68	3.54	1.54	
construction ability	1.00	1.65	2.58	3.64	2.63	
validity ability	0.88	1.61	2.48	0	1.33	1.53
application ability	0.89	1.56	2.48	3.50	1.36	
deployment ability	0.80	1.61	2.60	0	0.69	

In order to make the data more obvious, an average value is taken as the standard to draw the level diagram of 91 students' voltaic cell modeling ability, as shown in figure 1.

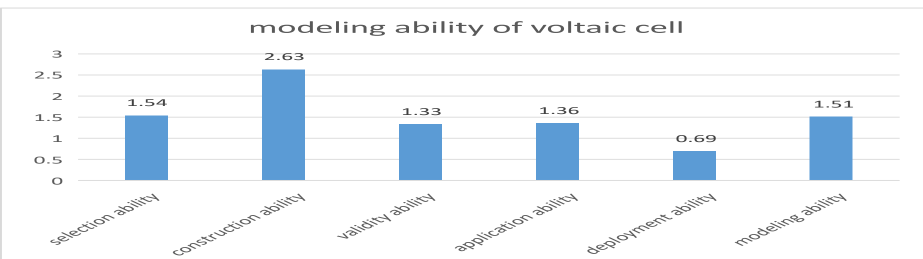


Figure 1. The modelling level of voltaic cell (N=91)

Table 9 and figure 1 indicate that students' average modeling ability level at all levels are generally less than 3 points. Only their model construction ability reached level 3. Most students only stay at level 2 in terms of their each level of modeling, and their average modeling ability only get 1.51 scores. Students only can say 2-4 voltaic cell constitute conditions and several microscopic concepts to explain the reason. It is difficult for them to contact the relationship between factors, and even more difficult to explain extension relationship. It is also difficult to grasp the relationship between electrode - electrolyte, electrode - redox reaction, electrolyte - internal circuit and the extended relationship they derive. It is shown that, for modeling, students cannot explain the relationship of internal structures and implicit knowledge from the relationship level and extend relationship level. Even if they have studied the scientific theory of voltaic cell and known the modeling process and rules, they still cannot choose the right materials completely by a scientific way and construct the scientific voltaic cell model. The results are consistent with the conclusions of Chang & Chiu, (2009).

The correlation analysis between modeling ability level and the academic achievement about voltaic cell

In order to understand the relationship among students' selection ability, construction ability, validity ability, application ability and deployment ability on the voltaic cell theme and the correlation between each modeling ability and students' performance, the correlation analysis of the modeling ability level and paper-pencil test scores of 91 students was conducted. The results are shown in table 9.

Table 9
The Correlation Analysis Between Modeling Ability Level and Academic Achievement About Voltaic Cell (N=91)

		Model selection	model construction	model validity	model application	model deployment	modeling ability	academic achievement
model selection	Pearson correlation coefficient;Sig(both sides)	1	.299** .004	.355** .001	.253* .016	.195 .063	.642** .000	.556** .000
model construction	Pearson correlation coefficient;Sig (both sides)		1	.189 .072	.002 .986	.142 .179	.623** .000	.557** .000
model validity	Pearson correlation coefficient;Sig (both sides)			1	.296** .004	.356** .001	.658** .000	.581** .000
model application	Pearson correlation coefficient;Sig (both sides)				1	.087 .41	.583** .000	.430** .000
model deployment	Pearson correlation coefficient;Sig (both sides)					1	.509** .000	.406** .000
modeling ability	Pearson correlation coefficient;Sig (both sides)						1	.837** .000

Note. **p<0.01, *p<0.05

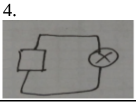
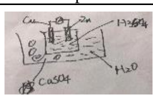
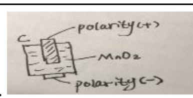
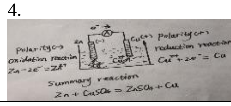
It can be seen from table 9 that students' academic performance and modeling ability are significantly correlated with 5 abilities, including selection ability, construction ability, validity ability, application ability and deployment ability (**p<0.01). Modeling capability is the comprehensive level of each modeling capability. The Pearson coefficient is between 0.4-0.6, indicating that students with high academic performance also have relatively strong modeling ability. When Pearson's coefficient is 0.837, students' academic performance is strongly correlated with the average modeling ability of students (**p<0.01). According to the principle of statistics, the probability of modeling ability will be as high as 0.837 if the student performs well. It can also be seen from the interview of students that students with high academic performance are more likely to have a comprehensive understanding of the constitute conditions and working principles of the voltaic cell leading to a good description and analysis of the connections between concepts and structures.

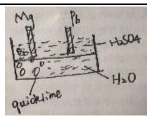
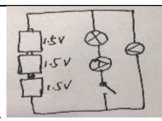
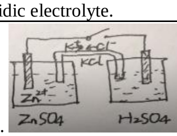
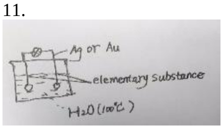
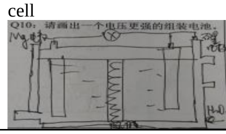
Among the five modeling abilities, selection ability was significantly correlated with construction ability, validity ability and application ability (**p<0.01, *p<0.05), which indicate that selection ability was the basis of construction ability, validity ability and application ability. However, there is no correlation between the selection ability and deployment ability the previous data shows that the deployment ability is almost one level lower than the selection ability which indicates that students are not aware of the limitations of the battery and cannot optimize it effectively. The result is consistent with the research results of Chang & Chiu (2009), but there are also some differences. According to the conclusion of Chang & Chiu (Chang, & Chiu, 2009), establishing the voltaic cell device is the basic level which students should reach. Fig. 1 also clearly shows that the level of construction ability is very high, while there is no correlation between model construction ability with validity ability, application ability and deployment ability. It shows that students can draw the basic device diagram but cannot apply the battery principle effectively in the new situation. In other word, the construction ability cannot be the benchmark of the ability of the latter three.

The difference analysis of modelling process about voltaic cell

In order to understand the mastery of voltaic cell during the modeling process, the concrete modeling process was transcribe into flow map as table 10 according to the interview record. The code 1-2 is for model selection, the code 3-5 for model construction ability, the code 6-7 for model validity ability, the code 8-9 for model application ability, the code 10-11 for model deployment. Analyzing is based on modeling level 1-4.

Table 10
Students' Modelling Process

the student in the level 1	the student in the level 2	the student in the level 3	the student in the level 4
1.Physical knowledge about circuit design and electrical	1.The knowledge of the galvanic cell, the conversion among thermal energy, chemical energy and electrical energy	1.The strength of the acid, electrode activity, the number of moving electrons in conductor	1.The knowledge about galvanic cell such as energy conversion from chemical energy to electric energy, two electrodes with different activity, electrolyte solution, spontaneous redox reaction and wires
2.Conductor	2.Quick lime, water, copper, zinc, dilute sulfuric acid, wire, high temperature resistant casing, baffle	2.Copper sheet metal, zinc metal, carbon, ammonium chloride, graphite rod, manganese dioxide	2.Copper and zinc metal; electrolyte solution with Cu^{2+} such as cupric sulfate solution in which redox reaction can take place by reacting with zinc; wire which can transfer electrons
3.Choosing a wire with good electrical conductivity	3.Shell must can resist high temperature which would be higher than 100 ℃, do not react with dilute sulfuric acid and has a rapid reaction rate	3.Cathode reaction: $Zn-2e^- = Zn^{2+}$ anode reaction: $2MnO_2+2e^- +2NH_4^+=Mn_2O_3+H_2O+2NH_3$	3.Zinc is lively as cathode occuring oxidation reaction; Cu is more innert than zinc as anode and Cu^{2+} occurs reduction reaction
4. 	 4.	 4.	4. 
5.Environmental protection, energy saving and no pollution	5. It can play the role of power supply in normal condition, and can speed up the discharge efficiency after removing baffle	5.Electrons move toward polarity(+) from polarity(-). anions move toward the anode. cations move toward cathode in electrolyte solution	5.Electrons move toward polarity(+) from polarity(-); SO_4^{2-} move toward the cathode, Cu^{2+} move toward the anode in the electrolyte solution; electrons in external circuit and ions in internal circuit form a closed loop

6.There would be no absolute advantage about galvanic cell	6.The concentration of sulfuric acid, the area of the zinc, the electrode activity	6.Metal activity, the concentration and temperature of electrolyte solution	6. One metal is more active and the other metal is more innert. The concentration of the electrolyte solution is greater and temperature is higher. The rate of redox reaction is faster and the discharge performance of battery is better
7.The current produced by battery can light bulb	7.The spontaneous redox reaction make voltage unbalance and generate an electric current because of the transfer of electrons. Check whether the light bulb glow or not when connected in the closed loop	7.It can prove that this method is feasible if the light bulb can glow when connected in the circuit	7.Connecting a light bulb in the circuit. phenomenon: zinc as cathode dissolves, copper as anode produces bubbles and the light bulb glows
8.Similarities: closed loop and wires; Difference: the way of forming circuit and making current which produced by ions in fruit is more cleaner and environment friendly	8.Similarities: the principle of active metal reacting with acid. Difference: the greater concentration of the acid, the higher efficiency of the generating electricity	8.Similarities: the principle, directional moving electrons which are in the electrolyte solution and form the electrical current. Difference: the anode, cathode, electrolyte and discharge intensity is different and it cannot be electric power storage	8.Similarities: the principle is similar, the cathode electrode is zinc, the anode electrode is Cu; the redox reaction is similar, zinc react with H^+ which was ionized from acid. Difference: electrolytes are different, one is the H_2SO_4, the other is citric acid; the discharge intensity is different
	9.Acid acts as electrolyte solution during reacting with zinc in the fruit battery	9.Fruit battery contains less electrolyte and the current is too small. So it is not convenient to carry and the battery cannot be recycled.	9.Fruit battery contains a little acid so the current is very small. Redox reaction caused a loss of electrolytes because they are in the same container. It is better to separate the redox reaction on the poles and separate the electrolyte in case that the anode contact with acidic electrolyte.
	10. 	10. 	10. 
	11. 	11.choosing a more stable electrode	11.replacing Cu-Zn galvanic cell with hydrogen-oxygen fuel cell 

It is found in table 10 that students at different levels express knowledge points at different levels in the specific modeling process. The higher the level is, the more content and the deeper of the knowledge is.

For the model selection process, high level students can point out the knowledge of the voltaic cell that will be used to make the battery. A voltaic cell is a device that converts chemical energy into electricity. The more active metal is the negative electrode, and the less active metal and non-metal is the positive electrode, such as Zn and Cu, or two graphite electrodes. They can also identify electrolyte solutions or ions, such as Zn^{2+} electrolyte solutions, and electrolytes in which electric charges can move. They are able to point out substances that undergo spontaneous redox reactions and the ability of wires to transmit electrons, and can connect sensitive galvanometers, light bulbs, LED lights and so on to form closed loop.

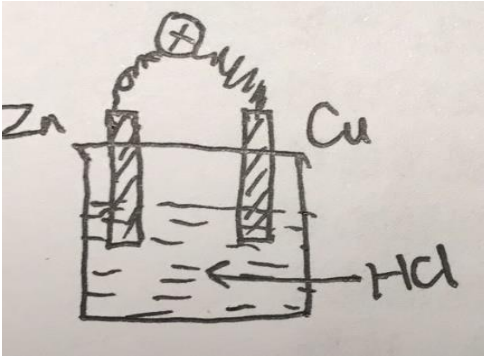


Figure 2-1 Cu-Zn-HCl voltaic cell (Level 2)

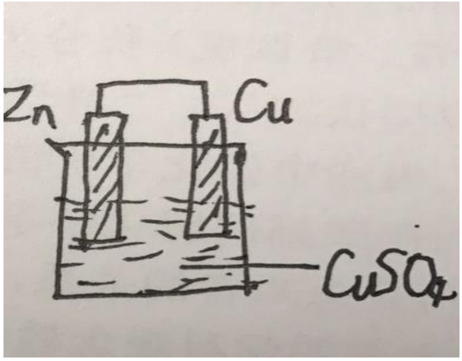


Figure 2-2 Cu-Zn-$CuSO_4$ voltaic cell (Level 2)

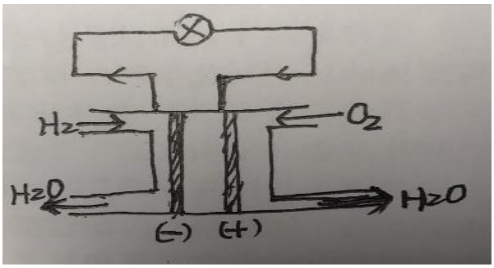


Figure 2-3 hydrogen-oxygen fuel cell(Level 3)

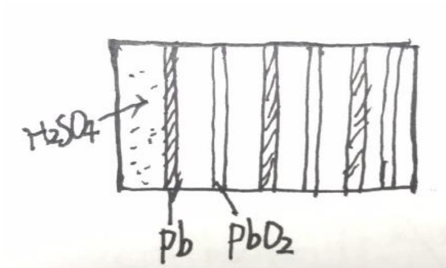


Figure2-4 lead storage cell(Level 2)

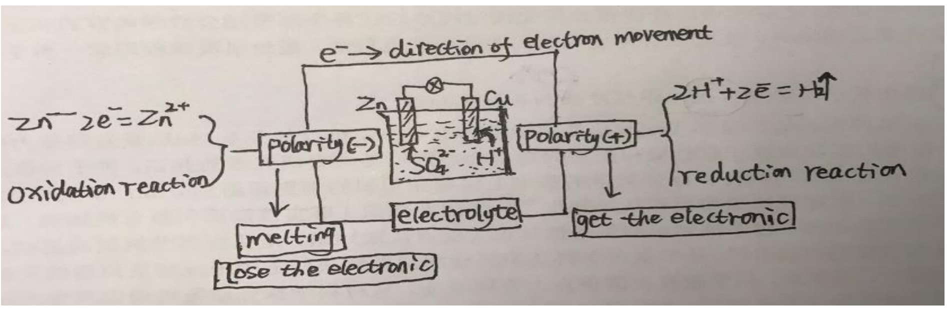


Figure 2-5 Cu-Zn-H_2SO_4 voltaic cell (Level 4)

Figure 2. Setup model of voltaic cell by students

For the modeling construction step, figure 2 shows the setup model drawn by some students:

The types of voltaic cell models that students can construct mainly include: Cu-Zn-H_2SO_4, Cu-Zn-HCl, Cu-Zn-$CuSO_4$. And students can construct hydrogen-oxygen fuel cell, dry cell and lead storage cell. However, the total students constructing these batteries are no more than 10%, indicating that students are more likely to build simple batteries, while slightly more complex ones are more difficult. Taking the voltaic cell in figure 2-5 as an example, high-level students can draw the basic structure diagram-electrode-electrolyte-wire-sensitive galvanometer, mark the names of each part, and note the movement-anion moving to anode (Zn pole) and cation moving to cathode (Cu pole). Writing the anode (Zn pole) equation: $Zn-2e-=Zn^{2}$, cathode (Cu pole) equation:

$2H^{+}+2e^{-}=H_2$, and overall equation: $Zn+H_2SO_4=ZnSO_4+H_2$. Answer the movement of electrons which is from anode (Zn) to cathode (Cu) and that of current which is from cathode (Cu) to anode (Zn). However, more students could not explain from energy conversion and fully understand the following working principle of the voltaic cell: oxidation takes place at the anode; electrons are transferred to cathode through external circuit; the oxidant gains electrons at the cathode occurring reduction reaction, so the electron transfer between the reducing agent and the oxidant is completed; the directional movement of ions in the solution between the electrodes and that of electrons in the external wire constitute a closed loop, which enables the two electrodes to react continuously and generate an orderly electron transfer process and a current.

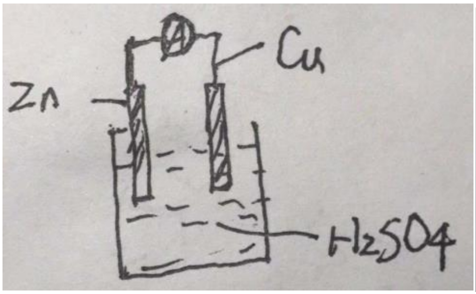


Figure 3-1 Cu-Zn-dilute H_2SO_4 voltaic cell

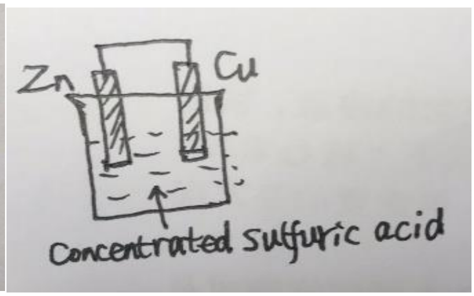


Figure 3-2 Cu-Zn-concentrated H_2SO_4 voltaic cell

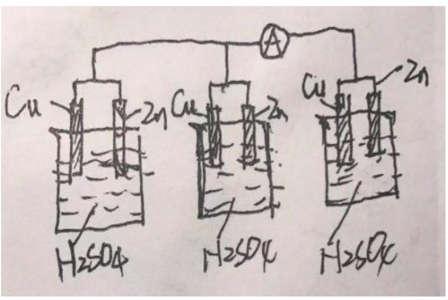


Figure 3-3 Series circuit Cu-Zn- H_2SO_4 voltaic cell

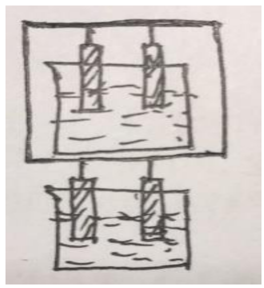


Figure 3-4 parallel connection Cu-Zn- H_2SO_4 voltaic cell

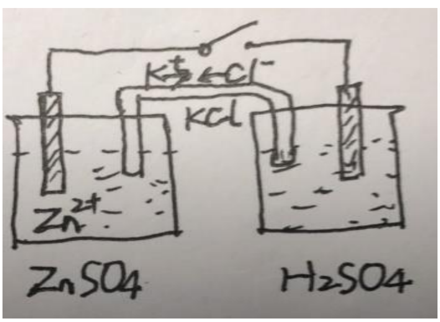


Figure 3-5 double fluid Cu-Zn- H_2SO_4 voltaic cell

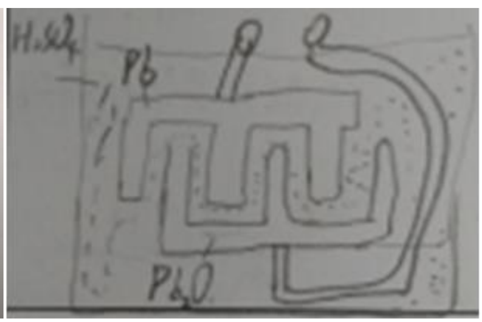


Figure 3-6 lead storage cell

Figure 3. The setup drawing by students in model deployment step

For model validity, the factors that influence the efficiency of the voltaic cell are mainly as follows: aluminum/copper area ratio, the contact area of Zn plate and solution, the concentration of dilute HCl, acid ionization of H^+, concentration of $CuSO_4$ solution, resistance of wire and other physical properties. Few students will think about the working efficiency of the voltaic cell from metal activity, such as the intensity of reaction between electrode metal sheet and hydrochloric acid, the difficulty of redox reaction and other factors. The main way to prove that the battery works is to add a light bulb /LED lamp/ammeter/sensitive ammeter to the circuit. If the lamp is on or the pointer is deflected, the device is feasible.

For model application, most students' answers to the similarities and differences between homemade battery model and fruit battery were described from a single perspective. Few students could explain the similarities and differences one by one from the four constitute conditions of the voltaic cell. Taking the self-made Cu-Zn-$CuSO_4$ voltaic cell and fruit battery as examples, the students mainly answered in the following aspects: the same electrode - the anode zinc and cathode copper; different electrolytes - the fruit battery electrolyte is orange juice and the copper and zinc voltaic cell is $CuSO_4$ with higher purity. Unlike the spontaneous redox reaction, the principle of fruit cell is that the acid juice of orange react with zinc, and that of the copper and zinc voltaic cell is the reaction of zinc and copper sulfate, which is more reactive. The reaction on cathode is different: the anode zinc of the two cell dissolves by losing electrons and becoming Zn^{2+} ions; Cu^{2+} ions gain electrons on cathode for Cu-Zn-$CuSO_4$ voltaic cell and fruit battery is H^+ in the solution to gain electrons, and the former is better at gaining electrons. While the limitation of fruit battery mainly focuses on the three aspects: less juice, less current and less portability.

For model deployment, the students' answers to draw batteries with higher voltage and longer life were mainly focused on ways to increase battery voltage and the battery life by using series circuits or increasing the concentration of electrolytes.

However, a few students are able to solve the problem from the limitation of the voltaic cell as the model diagram draw by part of students in this step shown in figure 3. Figure 3-1 is the diagram of the voltaic cell device drawn by students in the model construction step. Figure 3-2 shows that increasing the voltage by changing the concentration of the electrolyte H_2SO_4. However, the student ignores that copper will react with concentrated sulfuric acid if the electrolyte becomes concentrated sulfuric acid. The copper will be the anode, and zinc will be cathode. The negative electrode is copper and the positive electrode is zinc. Figure 3-3 increases the voltage by series. Figure 3-4 prolongs working life through parallel connection. Figure 3-5 and figure 6-6 show the model deployment process of high-level students. They know that the reason for the short life of the self-made battery is that the contact between electrode and electrolyte prevents some electrons from passing through electrode and external circuit. So it need to be separated into a dual fluid battery. Lead storage batteries are designed to extend their life by reusing.

To sum up, the biggest problem that students have during voltaic cell modeling is that few students mention that the function of the voltaic cell is to separate the redox reaction at the poles, form the current, and accelerate the transfer of electrons. It indicates that students are not well aware of the redox reaction which is one of the battery constitute conditions. The redox reaction is characterized by the change of the valence and the transfer of electrons. In physics, the directional movement of electrons creates an electric current. Students failed to combine the nature of the redox reaction with the battery working principle.

Conclusions and Suggestions on modelling process

Conclusions on modelling ability level

Based on the analysis of the modeling ability and modeling process of voltaic cell of senior one students, the following conclusions can be obtained:

(1) Students' modeling ability is generally low. The students' modeling ability of the voltaic cell theme is relatively low at all levels. Only the students with more construction ability can reach level 3. Model selection ability, model validity ability and model application ability are level 2. Model deployment ability can only reach level 1. The total modeling ability is level 2, and the average score of the voltaic cell modeling ability is 1.51. In terms of the distribution of students, the selection ability is normally distributed, while the construction ability is concentrated on the high level. The validity ability, application ability and deployment ability are all distributed in a normal (right-sided) state with few high-level personnel.

(2) Correlation analysis shows that students' modeling ability is positively correlated with their academic performance. Students' paper-pencil test scores and average modeling ability on original battery subjects were significantly correlated with each modeling ability (**$p<0.01$, *$p<0.05$), and the students with high modeling ability usually had good academic performance. Judging from the relationship among the five modeling abilities, selection ability were significantly correlated ($p < 0.01$, * * * $p < 0.05$) with construction ability, validity ability and application ability, which indicating that selection ability is their basis. However, there is no correlation between the selection and deployment ability, which suggesting that students cannot effectively optimize and improve its existing model if they cannot understand the limitation and application range of the voltaic cell.

(3) The modeling process of students have the characteristics of interpreting by a single factor. In the five modeling processes, model validity, model application and model deployment require students to explain the specific working principles, theoretical applications in new situations, constraints and optimization of models after establishing models. However, most of the students' answers are from a single perspective. It is difficult to fully explain the reasons from the connection and extension relationship between factors and the overall structure.

Research recommendations of modelling ability level

(1) Teaching based on models. From the research conclusion, students' model selection ability is the basis of their modeling ability, which affects the model construction, model application, model validity and model deployment in the new problem situation. how can the students choose if there are not the corresponding model to solve the problem in students' long-term memory system? Therefore, in the process of teaching, more attention should be payed to cultivate students' awareness of modeling and modeling for learning topics in textbooks and other learning materials. For example, voltaic cell theme models include disposable battery

model, rechargeable battery (secondary battery) model and fuel cell model. Fuel cell can be divided to acid, alkaline batteries and molten cells according to different electrolyte. These knowledge are the modeling basis for students' modeling learning of voltaic cells and problem solving. Teachers are required to help students conclude and construct corresponding voltaic cell models during learning.

(2) Focusing on understanding models. Owing to the fact that most students' modeling ability is at level 2 and the low relationship level and extended relationship level, students have a superficial understanding of the abstract relationship between the elements of the model structure and cannot understand the value of the model from the overall relationship of the model structure. For example, the basic elements of voltaic cell model include spontaneous electrode, electrolyte, redox reaction and closed circuit. Students should understand the relationship of the elements, the constraints of the relationship and the extend relationship deduced from the relationship, such as electrode-electrolyte, electrode-redox reaction, electrode-circuit, electrolyte-chemical reaction; Direction of electron movement, direction of ion movement, chemical reaction at anode and cathode. It is suggested that teachers and students should strengthen the understanding of model and modeling, such as the nature of model, cognitive process of models and modeling approach, so as to avoid simple model concepts and lack of modeling method.

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